

RADIATION PROTECTION

*Recommendations of
the International Commission on
Radiological Protection*

ICRP PUBLICATION 5

Report of Committee V
on the
Handling and Disposal of
Radioactive Materials in Hospitals
and Medical Research Establishments
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PREFACE

THIS report was begun under the Chairmanship of the late Dr. A. J. Cipriani, and was completed by the 1959–1962 Committee under the Chairmanship of Dr. C. P. Straub.

For the initial draft this Committee is indebted to Drs. A. J. Cipriani, A. Key and E. A. Watkinson, members of the 1953–1956 Committee. Members of the Committees who assisted in the preparation of the report submitted to the Commission included the following:

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The final revision has been undertaken by Mr. W. Binks (Great Britain). This publication also contains a reprint of the Commission's general recommendations, as amended to 1962.

REPORT OF COMMITTEE V
ON THE
HANDLING AND DISPOSAL OF RADIOACTIVE MATERIALS
IN HOSPITALS AND MEDICAL RESEARCH ESTABLISHMENTS

INTRODUCTION

(1) Since it is the Commission's wish to maintain fully its traditional contact with medical radiology and to fulfil its responsibilities to the medical profession, it is appropriate that the Commission should give general guidance on the precautions to be taken in the handling and disposal of radioactive materials by hospitals and medical research establishments.

(2) By utilizing the practices outlined in this report, it should in general be possible to maintain radiation doses below the maximum permissible levels recommended by the Commission. The national regulatory authorities should, however, draw up the necessary standards and control procedures.

(3) The Commission's Recommendations* refer to the following three categories† of exposed individuals :

First category : individuals who are occupationally exposed to radiation.

Second category : adults who work in the vicinity of controlled areas or who enter controlled areas occasionally in the course of their duties but who are not themselves employed on work involving exposure to radiation.

Third category : individual members of the population at large (including persons living in the neighbourhood of controlled areas).

In addition, the Commission gives separate recommendations about the exposure of the population as a whole.

(4) The present report is concerned with the following aspects of handling and disposing of radioactive materials as they relate to hospitals and small laboratories :

(a) the facilities to be provided in isotope laboratories and clinics and in wards and operating theatres ;

(b) the procedures to be adopted in handling, storing and transporting radioactive materials ;

(c) the procedures to be adopted in the safe disposal of radioactive waste products and contaminated materials.

(5) In the use of radioactive materials, two types of problems arise for which effective control must be provided. First, there is the health hazard to the worker from external sources and internally deposited radioactive materials, and to the people outside controlled areas‡ due to the transport and release of radioactive materials. Second, there is the contamination hazard which may adversely affect the results of the scientific work in progress and the future use of the building.

* See paragraph 36 of the Commission's recommendations at the end of this report.

† It should be noted that exposures within the first two categories defined here correspond to the two classes of exposure used in the International Labour Office's Radiation Protection Convention, namely, (1) workers directly engaged in radiation work and (2) workers not directly engaged in radiation work.

‡ See paragraphs 70d, 71 and 72 of Part 4 of the Commission's recommendations at the end of this report.

(6) In the past, radiation protection has been concerned mainly with protection of the worker and maintenance of a safe working environment. Thus, the emphasis has been on the individual as a worker, and the agencies having a responsibility in occupational health and a safe working environment were able to exercise the necessary degree of control over the industrial application and use of radioactive materials. With an expanding programme, the probability of exposing larger segments of the population to radioactive materials increases. The responsibilities for control in this area will vary, according to whether the materials are in transit or whether they are discharged into the atmosphere, ground sewerage system, or water course. Since, in most countries, different sections of governmental administration are responsible for these provisions, co-ordination is necessary to ensure that the total radiation dose to individuals and to the population does not exceed prescribed limits.

(7) In general, the standard of precautions required in the handling of radioactive materials depends on a large number of factors. As far as practicable, these factors have been indicated in the individual recommendations of this report. Some generalization has, however, been inevitable, and the recommendations must be interpreted and applied with judgement. In particular, some relaxations can properly be made when only very small amounts or concentrations of radioactive materials are being used.

(8) Although the recommendations are primarily directed at the control of radiation hazards in institutions, the Commission believes they should be applied, as far as is reasonably practicable, by all medical practitioners and medical research workers.

RESPONSIBILITY FOR RADIATION SAFETY MEASURES

(9) The authority having administrative control of an establishment will normally be responsible for the radiation safety of the operations as they affect its employees and the members of the public.

(10) In order to ensure that its responsibility is effectively met, the controlling authority should appoint one or more radiation protection officers, and also a suitably qualified medical adviser, to exercise medical supervision of the staff concerned. The work of the radiation protection officer(s) should include review of new designs for installations and equipment, review of programmes of work and advice on radiation problems.

(11) In each department in which radioactive materials are used, a radiation safety officer should be appointed from among the full-time employees of the institution concerned, to ensure that the radiation safety rules laid down by the controlling authority are carried out.

(12) The controlling authority shall ensure that all members of the staff concerned are adequately instructed about the radiation hazards they may meet and about the local radiation safety rules, including emergency procedures.

(13) Those working with radioactive materials shall be made aware of their duty to protect themselves and others from radiation hazards arising from their work. They, and their employers, should appreciate the consequences of a careless attitude toward radiation protection provisions. The general practice should be to work as far below the maximum permissible levels as is reasonably practicable. The application of the relevant precautions becomes more important with the larger amounts of radioactive material but should be applied even in dealing with low levels of radioactivity, since good working habits are essential. Bad example and careless working habits may unnecessarily expose associates or contaminate facilities outside the immediate radiation area.

MEDICAL EXAMINATIONS

(14) The functions of the medical adviser are :

- (a) to carry out pre-employment medical examinations of workers who are directly engaged in radiation work. The purpose of a pre-employment examination is to establish

the "normal" health status of an individual at the time of employment, firstly to assess his fitness to perform his duties without danger to himself or to others and secondly to provide a base line against which any subsequent change may be evaluated ;

- (b) to assess continuing fitness and to detect any deterioration in health ;
- (c) to advise on arrangements for first-aid treatment of radiation accident cases ; and
- (d) to make arrangements with appropriate hospitals for remedial treatment of cases following over-exposure.

(15) Medical examinations should be performed at a frequency depending on the conditions of work.

(16) The medical adviser may, at his discretion, require a complete blood count or any other special examination as part of the pre-employment medical examination or of any subsequent medical examination.

(17) When a person has received doses in excess of those permitted, or has an open wound contaminated with radioactive material, the medical adviser should decide whether it is necessary to carry out a medical examination, to arrange for remedial treatment or to recommend to the controlling authority that the person be suspended from employment, and for what period of time, as a worker directly engaged in radiation work.

PERSONNEL MONITORING

EXTERNAL RADIATION

(18) Doses received as a result of occupational exposures shall be systematically checked with appropriate instruments to ensure that the maximum permissible doses are not exceeded and to make it possible to keep individual cumulative dose records. It should not be forgotten that, in handling sources, the dose to fingers and hands may be much more significant than the whole-body dose ; in such cases, films or ionization chambers should, if practicable, be worn on the fingers or wrists as well as on the body. If these cannot be worn during specific operations, practice runs should be made which permit assessment of the actual exposures to the fingers and hands.

(19) It is the responsibility of the individual concerned to wear the supplied monitoring devices during the whole time that he may be exposed to radiation.

(20) Assessments should be made of the doses likely to be received by workers not directly engaged in radiation work ("second category"—paragraph 3). In the majority of cases, individual monitoring will prove to be unnecessary but occasional check monitoring will be desirable.

INTERNAL RADIATION

(21) It is sometimes necessary to make regular evaluations, by appropriate physical or chemical methods, of the amounts of various radionuclides which accumulate within the body of a worker, following intake by inhalation or ingestion or entry through wounds or absorption through the skin. Available information and methods permit meaningful estimates of body burden and of dose from internal radiation for only a small number of radionuclides. Specialist advice should be obtained on the evaluation of body burdens.*

(22) In a limited number of places, specialized equipment is available to estimate the total body burden of gamma-emitting radionuclides or of amounts of negative or positive beta-emitters large enough to produce measurable amounts of Bremsstrahlung or of annihilation radiation. For other materials, estimates are largely dependent upon a knowledge of relationships between body burden and the occurrence of the radionuclide in the blood stream or in excreta. For this purpose, concentrations in urine are most commonly measured, but in some cases examinations of the faeces may be more meaningful.

* The Commission has established a Task Group of Committee 4 to prepare general guidance on this subject.

(23) Sample-collection techniques defined by the examining laboratory should be followed. If the examination is called for as the result of a particular incident, the nature and time of the incident should be recorded insofar as they are known.

CONTAMINATION OF SKIN, HAIR and CLOTHING

(24) In addition to personnel monitoring of external radiation by means of film badges or pocket ionization chambers, the levels of radioactive contamination of the skin, hair and clothing should, where appropriate, be checked regularly so that procedures for dealing with any excess contamination can be put into operation.

RECORDS OF PERSONAL RADIATION DOSES

(25) Provision shall be made for maintaining a separate record of all measured doses received by workers directly engaged in radiation work ("first category"—paragraph 3). The retention of these records may be of considerable value in case of possible late effects. In some countries it is the practice to retain the records for 30 years after the last entry.

ENVIRONMENTAL MONITORING*

MONITORING PRIOR TO USE OF CONTROLLED AREA

(26) Before routine operations with radioactive materials commence, the working environment should be surveyed to determine the adequacy of facilities, equipment and safety precautions, and to provide a base line from which to judge the adequacy of radiation controls within the controlled area.

(27) When it is envisaged that the environment outside the controlled area may be significantly altered with respect to radiation hazards, adequate surveys should be made of the level of background radiation and of the radioactivity of air, soil or water. This will aid the identification of the operation responsible for any significant increase of the background radiation or the contamination of the area.

ROUTINE MONITORING

(28) Regular radiation surveys should be made, at a frequency dictated by the operations within the controlled area, to determine the adequacy of safety procedures. Such surveys should include checks of the facilities and equipment (shielding, storage, hoods, respirators, ventilation, etc.) and of the working techniques and, where there is any reasonable probability of a significant radiation hazard existing, of the vicinity of the controlled area. A radiation survey should also be carried out if personnel monitoring tests indicate that the doses received exceed, or are likely to exceed, the maximum permissible levels, and if enquiries have failed to reveal the cause.

(29) If any survey indicates that, under normal operating conditions, personnel may receive doses in excess of those permitted or of those judged necessary for the work, the radiation protection officer should indicate the action to be taken to rectify the situation.

(30) Records should be maintained of the general results of all surveys and the detailed results of surveys following major changes in the radiation pattern.

GENERAL AIMS AND PROCEDURES FOR WORK WITH SEALED SOURCES†

(31) Sealed sources present potential hazards of external exposure from beta, gamma and sometimes neutron radiation, and of internal exposure resulting from inhalation and ingestion of radio-

* The Commission has established a Task Group of Committee 4 to prepare general guidance on this subject.

† Additional details relating to protection from sealed sources will be found in ICRP Publication 3 (Report of Committee III on Protection Against X-Rays up to Energies of 3 MeV and Beta and Gamma-rays from Sealed Sources).

active material that may escape from the source. Precautions should therefore be taken to guard against both external and internal radiation hazards, although only rarely will the internal hazard arise.

(32) Wherever practicable, sealed sources should be labelled and thereby be identifiable as to the nature and activity of the radioactive material contained. Such labelling is not necessary if a source is considered to present no external or internal radiation hazard. For example, sealed sources could normally be regarded as not requiring labelling if they contain not more than 1 μCi of Group 1 radionuclides (see Table 1) or up to 100 μCi of other Groups of radionuclides and have a dose rate not exceeding 10 mrad/h (measured in air) at or near the surface of a container which emits beta or gamma radiation, or have a "dose equivalent" rate not exceeding 10 mrem/h at or near the surface of a container which emits neutrons.

(33) A separate room should be provided for the "make-up" and cleaning of sources and applicators and should be adequately ventilated. It should be occupied only when such work is in progress.

(34) The number and position of removable sealed sources in or on patients receiving treatment should be regularly checked and dressings from such patients should not be disposed of until all the sources used have been accounted for. As an additional precaution, dirty dressings and excreta may be monitored.

EXTERNAL RADIATION

(35) Whether the source is in use or in storage*, steps should be taken to ensure that over-exposure of people cannot take place in normal circumstances. Sufficient shielding and working distance should be provided for this purpose. Exposure can also be limited by controlling the working time spent in the radiation field. The radiation dose received by the operator often depends critically on the working procedure adopted. The specifications of these procedures should, therefore, form part of the protective measures. Warning signs and barriers may have to be erected to prevent unauthorised entry into significant radiation fields.

(36) Sealed sources should never be picked up with the fingers. They should be manipulated with appropriate handling equipment or implant instruments. Handling equipment should be easy and convenient to use; cumbersome and heavy tools should be avoided since the longer time required to manipulate them may result in needless exposure. The sources themselves should be so designed that they can be quickly and easily cleaned. In certain types of work, particularly in the making up of medical applicators, experienced operators occasionally receive high doses even when practicable shielding and remote handling equipment are used. With properly trained, experienced operators, it is possible in general to keep the dosage below the maximum permissible level. In cases where it becomes necessary to institute a rota system of duties in order to avoid over-exposure of personnel, both the procedure and design should be reviewed.

(37) It should be appreciated that sealed sources containing pure β -ray emitters may emit Bremsstrahlung or characteristic X-rays or annihilation radiation. Any hazard from such radiations should be evaluated and the necessary precautions taken. Since some β -ray emitters are also γ -ray emitters, they should be protected as such (see ICRP Publication 3).

(38) A source intended for use in β -ray therapy requires a thin "window". When the source is not in use, the window should be adequately shielded to stop all β -rays. When it is necessary to clean the window, care should be taken to prevent its being damaged and to minimize the exposure of personnel.

INTERNAL RADIATION

(39) The possibility of ingesting or inhaling radioactive material arises if a sealed source starts to leak. It is important, therefore, that sealed sources should be constructed in such a way that the

* Advice on the storage and transportation of sealed sources is given in sections beginning at paragraphs 98 and 109.

likelihood of leakage is minimized and that they should be used in such a way that rupture of the container is unlikely. For the latter reason, care should be taken to prevent bending, dropping, or over-heating of sources.

(40) Even when the above precautions have been taken, every sealed source should be tested for leakage or surface contamination both initially and periodically and a record kept of the results of such tests*. With simple equipment, amounts of free activity of 0.01 to 0.1 μCi are readily detectable.

(41) A leaking source should be placed in an airtight container but heat sealing—as in a glass tube or by soldering a metal container—should be avoided if there is a risk of aggravating the damage by over-heating the source. Arrangements should then be made with the manufacturer or some qualified laboratory to receive the source for repair. The package should be so prepared that no contamination will result during transportation. For emergency procedures following a spill or leakage or a loss of a sealed source, see paragraphs 70 to 72, and 108.

STERILIZATION OF SMALL SEALED SOURCES

(42) When small sealed sources are sterilized (e.g. radium needles), care should be taken to minimize the radiation exposure of staff, and to avoid damage to, or loss of, the sources. Examples of methods of carrying out such sterilization are given in Appendix B.

GENERAL AIMS AND PROCEDURES FOR WORK WITH UNSEALED RADIOACTIVE MATERIALS

(43) The design and facilities of laboratories, isotope clinics, wards and operating theatres, the design of all medical and experimental equipment, and the general working procedures should be aimed at:

- (a) minimizing the exposure of staff;
- (b) limiting the doses to patients to the minimum levels consistent with medical requirements;
- (c) protecting visitors and other patients when in proximity to patients undergoing treatment with sealed or unsealed radionuclides; and
- (d) controlling the spread of radioactive material into the working environment.

(44) In dealing with unsealed radioactive materials, special attention should be paid to internal radiation hazards. This section gives detailed guidance on controlling such hazards. The extent of the precautions to be taken will depend upon a number of factors such as the nature of the operations, the total activity, the specific activity, the radiotoxicity, the chemical toxicity and other chemical and physical properties of the radionuclides or radioactive compounds. However, even when the internal radiation hazards are small, there may still be external radiation risks in handling radioactive materials, in which case measures similar to those recommended for sealed sources will apply.

CLASSIFICATION OF RADIONUCLIDES

(45) The information given in Table 1 of ICRP Publication 2†, regarding maximum permissible concentrations of various radionuclides in air, serves as a basis for a classification of radionuclides

* In Appendix A guidance is given on methods of testing sealed sources for leakage or surface contamination and on the levels of free activity below which a source may be regarded as free from leakage or surface contamination.

† Report of Committee II on "Permissible Dose for Internal Radiation" (1959).

according to relative radiotoxicity. Such a classification, based on one drawn up by the International Atomic Energy Agency*, is given in Table 1 below†.

TABLE 1. CLASSIFICATION OF ISOTOPES ACCORDING TO RELATIVE RADIOTOXICITY PER UNIT ACTIVITY

Group 1‡

Pb-210	Po-210	Ra-223	Ra-226	Ra-228	Ac-227	Th-227	Th-228	Th-230
Pa-231	U-230	U-232	U-233	U-234	Np-237	Pu-238	Pu-239	Pu-240
Pu-241	Pu-242	Am-241	Am-243	Cm-242	Cm-243	Cm-244	Cm-245	Cm-246
Cf-249	Cf-250	Cf-252						

Group 2‡

Na-22	Cl-36	Ca-45	Sc-46	Mn-54	Co-56	Co-60	Sr-89	Sr-90
Y-91	Zr-95	Ru-106	Ag-110m	Cd-115m	In-114m	Sb-124	Sb-125	Te-127m
Te-129m	I-124	I-126	I-131	I-133	Cs-134	Cs-137	Ba-140	Ce-144
Eu-152 (13 y)		Eu-154	Tb-160	Tm-170	Hf-181	Ta-182	Ir-192	Tl-204
Bi-207	Bi-210	At-211	Pb-212	Ra-224	Ac-228	Pa-230	Th-234	U-236
Bk-249								

Group 3‡

Be-7	C-14	F-18	Na-24	Cl-38	Si-31	P-32	S-35	A-41
K-42	K-43	Ca-47	Sc-47	Sc-48	V-48	Cr-51	Mn-52	Mn-56
Fe-52	Fe-55	Fe-59	Co-57	Co-58	Ni-63	Ni-65	Cu-64	Zn-65
Zn-69m	Ga-72	As-73	As-74	As-76	As-77	Se-75	Br-82	Kr-85m
Kr-87	Rb-86	Sr-85	Sr-91	Y-90	Y-92	Y-93	Zr-97	Nb-93m
Nb-95	Mo-99	Tc-96	Tc-97m	Tc-97	Tc-99	Ru-97	Ru-103	Ru-105
Rh-105	Pd-103	Pd-109	Ag-105	Ag-111	Cd-109	Cd-115	In-115m	Sn-113
Sn-125	Sb-122	Te-125m	Te-127	Te-129	Te-131m	Te-132	I-130	I-132
I-134	I-135	Xe-135	Cs-131	Cs-136	Ba-131	La-140	Ce-141	Ce-143
Pr-142	Pr-143	Nd-147	Nd-149	Pm-147	Pm-149	Sm-151	Sm-153	Eu-152
Eu-155	Gd-153	Gd-159	Dy-165	Dy-166	Ho-166	Er-169	Er-171	(9.2 hr)
Tm-171,	Yb-175	Lu-177	W-181	W-185	W-187	Re-183	Re-186	Re-188
Os-185	Os-191	Os-193	Ir-190	Ir-194	Pt-191	Pt-193	Pt-197	Au-196
Au-198	Au-199	Hg-197	Hg-197m	Hg-203	Tl-200	Tl-201	Tl-202	Pb-203
Bi-206	Bi-212	Rn-220	Rn-222	Th-231	Pa-233	Np-239		

Group 4‡

H-3	O-15	A-37	Co-58m	Ni-59	Zn-69	Ge-71	Kr-85	Sr-85m
Rb-87	Y-91m	Zr-93	Nb-97	Tc-96m	Tc-99m	Rh-103m	In-113m	I-129
Xe-131m	Xe-133	Cs-134m	Cs-135	Sm-147	Re-187	Os-191m	Pt-193m	Pt-197m
Th-232	Th-Nat	U-235	U-238	U-Nat.				

* International Atomic Energy Agency (Vienna). Technical Reports Series No. 15—A Basic Toxicity Classification of Radionuclides (1963).

† An alternative classification has been suggested by K. Z. Morgan, W. S. Snyder and M. R. Ford, *Health Physics*, **10** (3), 151, 1964.

‡ The International Atomic Energy Agency refers to Groups 1 to 4 as "High Toxicity", "Medium-Toxicity—Upper Sub-Group A", "Medium Toxicity—Lower Sub-Group B" and "Low Toxicity" respectively.

CLASSIFICATION OF LABORATORIES

(46) For convenience in discussion, laboratories designed for handling low levels of radioactivity are described as Type 1, for intermediate levels as Type 2, and for high levels as Type 3. The amount of any given radionuclide that can be handled at one time will vary according to the type of laboratory available, and the type of laboratory suitable for any given amount of material will vary with its toxicity. Table 2 gives a classification of types of laboratories required for various amounts of radionuclides in the groups defined in Table 1. It is unlikely that, at present, there will be the need for a Type 3 laboratory for clinical work in hospitals.

TABLE 2. CLASSIFICATION OF LABORATORIES FOR HANDLING RADIONUCLIDES

Group of Radionuclide	Type of laboratory required for levels of activity specified below		
	Type 1	Type 2	Type 3
1	< 10 μ Ci	10 μ Ci to 1 mCi	> 1 mCi
2	< 1 mCi	1 mCi to 100 mCi	> 100 mCi
3	< 100 mCi	100 mCi to 10 Ci	> 10 Ci
4	< 10 Ci	10 Ci to 1000 Ci	> 1000 Ci
Modifying factors (see text)			Factors
Simple storage			$\times 100$
Very simple wet operations (e.g. preparation of aliquots of stock solutions)			$\times 10$
Normal chemical operations (e.g. analysis, simple chemical preparations)			$\times 1$
Complex wet operations (e.g. multiple operations, or operations with complex glass apparatus)			$\times 0.1^*$
Simple dry operations (e.g. manipulation of powders) and work with volatile radioactive compounds			$\times 0.1^*$
Dry and dusty operations (e.g. grinding)			$\times 0.01^*$

(47) It is apparent that no exact definition of these requirements is given in Table 2. To attempt to do so would give a misleading impression of precision, because many factors must be considered that do not appear in the table. Experienced people can work safely with equipment which might be dangerous in the hands of beginners, and no weight has been given to difficulties of manipulation caused by the shielding and remote handling required by γ -emitters.

(48) Numerical values can be assigned to certain additional factors, and this is done by applying the "modifying factors" given beneath Table 2. If, for example, normal chemical operations are to be carried out with up to 10 mCi of a Group 2 radionuclide, a Type 2 laboratory would be required. However, 100 mCi (i.e. 10 mCi $\times$ modifying factor 10) of such material could be used

* These factors could be increased by one or more orders of magnitude if the operations are carried out in closed boxes.

if only aliquots were to be prepared, but if the work were to consist of grinding Group 2 material, only 100 μCi (i.e. 10 mCi $\times$ modifying factor 0.01) could be handled in this laboratory unless a closed box is used.

(49) The nature of Table 2 is such that the actual selection of amounts of radionuclides to be handled is a matter for judgement. If a quantity of radioactive material, after applying any modifying factors, falls within a factor of 2 or 3 of a dividing line between classes of laboratory, then guidance should be given by the radiation protection officer, bearing in mind factors such as experience of staff, availability of emergency services, and other things which cannot be expressed numerically.

FACILITIES FOR WORK WITH UNSEALED RADIOACTIVE MATERIALS

(50) One of the cardinal principles in the use of radioactive materials is that the facilities should be separated from other facilities insofar as is practicable, much in the same way that bacteriological laboratories dealing with pathogenic organisms, or laboratories handling toxic agents, are separated from other laboratories. (For further details regarding the lay-out and facilities for a Type 2 laboratory, see Appendix C.)

(51) Floors should have smooth, continuous and non-absorbent surfaces and should be made of materials that can be cleaned easily and possess a surface that can be removed easily.

(52) Walls and ceilings should be finished with a non-porous washable surface, such as a good hard-gloss paint.

(53) Special attention should be given during the planning stage to such aspects as the mode of heating (e.g. enclosed wall heaters or under-floor heaters rather than small wall radiators which are difficult to decontaminate), the ventilation, and the design of drains. It should be appreciated that the use of closed boxes fitted with gloves or remote-controlled manipulators will lead to a reduction in capital and running costs of heating and ventilation of laboratories where therapeutic quantities of radionuclides are to be dealt with.

WORKING PROCEDURES WITH UNSEALED RADIOACTIVE MATERIALS

(54) Good working procedures are so important that techniques must be well thought out and understood before work is undertaken. These procedures should be tried out by practice runs so that when radioactive material is used, operations are performed speedily and confidently with minimum exposure and risk of accident. A balance should be struck between hurried manipulations, which cause accidents, and prolonged operations, which may lead to excessive exposure. Working procedures should be reviewed by the radiation protection officer.

(55) Maintenance work, e.g. on laboratory equipment, ducts, or waste pipes, should be undertaken only after preliminary monitoring. If ducts or pipes are opened up during the work, monitoring of air and surfaces should be undertaken as the work progresses.

(56) Working surfaces in the laboratory should be covered, and manipulations should be carried out over trays made of non-absorbing substances (e.g. stainless steel, enamelled metal, polyethylene) lined with absorbent material (e.g. paper). It should be remembered, however, that the use of flammable materials introduces a fire hazard. In such cases it may be better to omit the lining material.

(57) Work involving spray, dust, fume or gas should be carried out in a hood or closed box. When the work is completed, the worker should clean his contaminated material and, if necessary, arrange for its disposal. Trays and bench surfaces should also be cleaned after work. Suitable waste cans should be provided (see Appendix C). They should be monitored and changed with sufficient frequency to ensure that they do not become a hazard.

(58) Vessels containing radioactive material should be covered when not in use.

(59) The use of mouth-operated pipettes and wash-bottles shall not be permitted in controlled areas. Special techniques are available which avoid glass blowing by mouth and these should be used in controlled areas whenever practicable.

(60) Eating, smoking and the application of cosmetics should not be permitted in controlled areas or clinics where unsealed radioactive materials are being handled or used. Such personal habits as sucking pencils and fingers should be discouraged.

(61) The unbroken skin is an effective barrier against direct entry of many radioactive materials into the blood stream, so precautions should be taken to avoid cuts and puncture wounds. If there are open wounds on exposed parts of the body, no work should be permitted with the more hazardous materials or larger quantities of the less hazardous ones unless the wounds are properly dressed and protected. Cracked or chipped vessels should not be used in controlled areas.

(62) The type of protective clothing required in laboratories depends upon the amount of radioactivity. The handling of even tracer amounts will require laboratory coats over normal attire. When large quantities of radioactivity are handled, coveralls or other clothing that completely cover the body should be worn. The use of such clothing should be restricted to these operations. In such operations the risk of contamination may also require the use of special shoe coverings or the provision of shoes for use only in controlled areas. Rubber gloves should be worn when there is a likelihood of contaminating the hands.

(63) As regards ward procedures, general rules should be issued to nurses in charge of wards. These should indicate any limitations of the time that ward staff and visitors may spend in proximity to patients containing therapeutic quantities of sealed or unsealed radioactive materials. Instruction sheets should also be drawn up, summarizing the techniques to be followed by the staff for particular isotopes. In all cases, the handling of contaminated articles (e.g. bed linen, patients' clothing, towels and china) should be reduced to a minimum.

CONTAMINATION CONTROL

(64) An essential feature of contamination control is regular and proper cleaning of controlled areas. Cleaning should be done by someone aware of the need for taking precautions; cleaners without special training are not suitable for this purpose. Guidance on "permissible" levels of surface contamination is given in Appendix D.

(65) Cleaning equipment (mops, brushes, rags, buckets, wax, soap, etc.) should be restricted to controlled areas and not used elsewhere. Such equipment should be monitored periodically and, if necessary, disposed of as radioactive waste. Floors, benches and furniture should be cleaned by a vacuum cleaner equipped with a high-efficiency filter or by a wet or moist method. Dry sweeping should be avoided.

(66) Special attention should be paid to techniques for avoiding the build-up of contamination on gloves used more than once and for avoiding the transfer of contamination from the gloves to parts of the body.

SPILLS OF RADIOACTIVE MATERIALS

(67) Spills will occur and it should be the responsibility of the person who causes the spill to notify the proper person to ensure that it is effectively cleaned up. If the amount of radioactive material used is no greater than that needed to carry out the given operation, the seriousness of spills and of exposure to personnel in normal work will be reduced.

(68) Any spill should be dealt with immediately, but appropriate action will vary with circumstances. Local procedures for dealing with spills, therefore, should be drawn up and posted in the laboratories.

MINOR SPILLS

(69) Absorbent paper should be laid immediately over a wet spill. Dry spills should preferably be removed by wet methods, using wet absorbent paper to prevent dispersion, if necessary. Alternatively, a vacuum cleaner equipped with a high-efficiency filter could be used. Any paper used should then be removed to a suitable waste receptacle and the affected area monitored. Decontamination should be carried out until the surface levels are below the appropriate prescribed levels (see Appendix D). Swabbing should always be done inward toward the centre of the spill. If contamination levels cannot be sufficiently reduced, the surface should be stripped or covered. In all of these operations, great care should be taken to avoid spread of the radioactivity and to prevent contamination of clothing, skin and monitoring instruments.

EMERGENCIES (Serious spills or fires)

(70) Local emergency instructions should be drawn up for all controlled areas where the quantities of radioactive material used are such that a serious spill or fire is capable of causing excessive exposure. These instructions must be seen and read by all persons who may be concerned.

(71) The best course of action in an emergency will depend on the nature of the emergency and on local circumstances. However, in all cases the first concern should be the protection of the persons involved, including patients (whether in the operating theatre, treatment cubicle or ward). The second concern should be the limitation of the spread of radioactive contamination. The local emergency instructions might be based on the example given in Appendix E.

(72) Certain basic equipment should be available for use in emergencies. This should include monitoring equipment, coveralls, caps, gloves and overshoes. Suitable respirators may also be required. Large bags made of heavy paper are useful for quick disposal of contaminated material. Several rolls of sticky tape should be available for sealing the disposal bags and, if it should prove necessary, for sealing off a room contaminated by radioactive materials.

DECONTAMINATION OF PERSONNEL

DECONTAMINATION OF INTACT SKIN

(73) Persons who have handled radioactive materials should wash their hands thoroughly with soap and water before leaving a controlled area. After washing, the hands should be checked for contamination. If contamination is present after several washings the case should be referred to the medical adviser. Cleaning methods that seriously damage the skin should be avoided. However, it may be necessary to use powerful chemical reagents when ordinary cleaning methods fail. Moderate activity that remains fixed to the skin after the application of the above procedures may be less harmful than employment of harsher decontamination measures.

(74) Great care should be taken during decontamination of the face to avoid further contamination of the lips and eyes. If the eye is being irrigated, it should be ascertained that the adjacent skin is not highly contaminated; measures should be taken first to prevent such contamination from being washed into the eye. The eye should be irrigated outwards to avoid contamination of tear ducts.

DECONTAMINATION OF INJURED SKIN

(75) When corrosive or other toxic materials are present in addition to radioactive contaminants, the usual first-aid measures should be applied before attempting to carry out radioactive decontamination.

(76) If the skin is accidentally broken when working with radioactive materials, the wound should be irrigated immediately with tap water, the edges of the gash being spread to assist the flushing action of the water, and to encourage bleeding. All wounds of this nature should be referred

to the medical adviser as soon as first-aid measures have been started, so that steps can be taken to free the wound from contamination.

RADIOACTIVITY DEPOSITED IN THE BODY

(77) In the case of an accidental intake of radioactive materials, which it is believed may lead to a significant dose of internal radiation, the medical adviser should be called immediately. Pending arrival of the medical adviser, certain simple first-aid measures may be applied to assist in the elimination of the radioactivity. These include the cleansing of the nasal passages, the expectoration of saliva and, perhaps in some cases, the induction of vomiting.

DECONTAMINATION OF BUILDINGS, EQUIPMENT AND CLOTHING

BUILDINGS

(78) Good operating methods and routine cleaning will normally keep contamination levels in the working areas below prescribed limits (see Appendix D). Special decontamination procedures will, however, be needed after spills and when a laboratory ceases to be used for work with radioactive materials.

(79) Such decontamination should start with conventional cleaning methods, but special precautions may be required. If these conventional methods fail to reduce the contamination to below the prescribed limits, additional measures will be needed.

(80) In general, short lived contamination of a half-life less than a month may be covered, after scrubbing to remove loose contamination. Substantial, long-lived contamination remaining after scrubbing may necessitate the covering or removal of the contaminated surfaces. If the contamination is covered, precautions must be taken against subsequent escape and the area should be marked.

EQUIPMENT

(81) Equipment may often be cleaned by washing with detergent followed, if necessary, by the use of complexing agents or ultrasonic methods. Equipment which cannot be decontaminated below prescribed levels, or be retained until the activity has decayed below prescribed levels, and for which further use cannot be found, e.g. in more active areas, should be discarded as radioactive waste.

CLOTHING

(82) Any article of protective clothing or personal clothing found to be contaminated should be placed in a container provided for the purpose.

(83) Contaminated protective clothing should not be released to public laundries unless the activity is below prescribed levels (Appendix D). For articles contaminated above these levels with short-lived radionuclides, storage is recommended until the activity has fallen below the indicated levels.

(84) In the case of heavily contaminated clothing, precautions should be taken against external radiation and possible inhalation of dispersed radioactivity.

(85) Where special laundering facilities are available as, for example, in a hospital or an atomic energy establishment, such clothing may be laundered. It should not, however, be laundered with uncontaminated articles of clothing or bedding. The procedures should be reviewed by the radiation protection officer and the decontaminated articles should be monitored before re-use. If the contamination cannot be reduced to prescribed levels, the garments should be treated as radioactive waste.

DISPOSAL OF RADIOACTIVE WASTE

(86) The authority having administrative control of an establishment will be responsible for arrangements for the safe disposal of any radioactive waste that may arise. The Commission realizes that the factors influencing the procedures for the disposal of radioactive waste vary from country to country and, therefore, stresses that disposal should be in accordance with the regulations or codes of practice in operation in each country. General guidance for those responsible for drawing up national regulations or codes of practice is given in Appendix F.

(87) It is convenient to recognize three main types of waste, namely, liquid, solid and gaseous. As regards hospitals and medical research establishments, the waste may comprise excreta from patients undergoing diagnosis or therapy with unsealed radionuclides, unwanted solutions of radionuclides, normal low-level liquid waste, normal low-level solid waste (e.g. paper, glass, carcasses of experimental animals), sealed sources, waste from spills and decontamination, and gases.

DISPOSAL OF LIQUID WASTES

(88) For small quantities of soluble radioactive wastes containing nuclides of short half-lives, the most convenient and, generally, the most practicable procedure is disposal into the sanitary sewerage system. This provides a period of delay for decay before the radioactive materials can reach water or food supplies, and also provides some degree of dispersal or dilution.

(89) Direct discharge into the sanitary sewerage system is particularly satisfactory for the disposal of excreta from patients given radioactive materials in medical diagnosis and therapy.

(90) Valid estimates of quantities of radioactive wastes which may appropriately be released into sewerage systems will depend on local factors. However, under conditions representative of most hospitals and medical research establishments using diagnostic or tracer quantities of radionuclides, discharges which correspond to concentrations (averaged over, say, 1 month) in the range of 10^{-4} to 10^{-5} $\mu\text{Ci/ml}$ in the effluent from the establishment will usually be sufficient to allow disposal of the wastes which arise.

(91) For wastes containing radionuclides which cannot appropriately be discharged immediately to the sewerage system because of their long half-lives or high activities, the alternatives are utilization of specialised waste disposal services or storage.

DISPOSAL OF SOLID WASTES

(92) Solid waste which is only lightly contaminated may be disposed of with ordinary waste. A few microcuries in an ordinary waste bin would not be hazardous. Occasional releases up to 100 μCi of radionuclides other than those in Group 1 would also be non-hazardous.

(93) For larger amounts of radioactivity other disposal methods, including incineration or burial, should be used; indeed, these methods may be preferable even for activities less than 100 μCi .

(94) Incineration can sometimes be an effective method of disposal for radionuclides which form gaseous products when the refuse is burned. Tritium, carbon-14 and iodine-131 are examples. The amount of waste arising from the use of carbon-14 and, at present, of tritium, in hospitals and medical research establishments, is rarely great enough to preclude disposal by incineration or burial. In the case of iodine-131, it is normally possible to dispose of millicurie amounts per day by incineration.

(95) Under suitable conditions, burial of waste to a depth of at least one metre in a municipal dump can be employed as a method of disposal with radionuclides dispersed throughout the waste, and for wastes in a form unattractive for salvage.

(96) The problems presented by small sealed sources are somewhat different. Here the activity is in a concentrated, manageable form. The waste is the original source which has decayed to a

level of activity too low for economical use. It is recommended that sources having activities greater than 10 μCi should not be disposed of with refuse. The sources should be stored until decay permits local disposal by ordinary methods or should be collected in any national disposal areas set aside for this purpose.

DISPOSAL OF AIRBORNE WASTES

(97) Airborne wastes will originate mainly from the stores (especially radium stores in hospitals), from the incineration of solid combustible wastes and from laboratory fume hoods and closed boxes. It is important that the points of release to the atmosphere be carefully sited. Consideration should also be given to the necessity of using filters in the exhaust system (see Appendix C).

STORAGE OF RADIOACTIVE MATERIALS

(98) Each hospital or medical research establishment should be provided with one or more main areas where radioactive materials, when not in use, may be stored. Each area should be properly marked with approved warning signs, and pertinent regulations regarding its use should be posted at points of access. Where access to the area might otherwise be available to unauthorized individuals, a lock should be provided to prevent deliberate or inadvertent entry into the storage area or compartment.

(99) The area should be so located as to simplify transport problems but care should be exercised to ensure that radiation backgrounds in adjacent areas are acceptable. To minimize exposure of staff resulting from the transport of sources, stores should, where practicable, be located near working areas; e.g. the radium store and "make-up" room might be near to the radium theatre. There should be a storage area where samples of urine and faeces can be temporarily stored. When such samples are of high-activity it may be necessary to use a shielded container.

(100) Where radioactive gases or vapours may be emitted by stored sources, the store should be adequately ventilated by mechanical means.

(101) Procedures for the introduction and withdrawal of material and the requirements for storage containers and labelling should be prescribed by a responsible person, for example, a radiation protection officer. The store should be used only for the storage of radioactive material. Adequate records should be kept of all stored radioactive materials with a check-in and check-out system for sources that are used frequently. Periodic inventories should be performed and made a matter of record.

(102) Consideration should also be given to (a) shielding, (b) contamination control and (c) flooding, fire and theft, as discussed below.

SHIELDING

(103) Radioactive materials may emit combinations of alpha, beta and gamma radiation, and neutrons. Shielding is not normally required for alpha radiation. Shielding should be provided for gamma-emitting radionuclides to protect not only those who enter the room, but those in adjacent areas. (Information on shielding against gamma-emitting sources is given in ICRP Publication 3). Sources emitting only beta radiation should be stored in containers which will reduce the radiation to negligible levels. It is often convenient to use transparent materials; 4 to 5 mm of glass or 7 to 8 mm of plastic will usually suffice. With very large sources, additional precautions may be needed against Bremsstrahlung. Paraffin or other hydrogenous materials are convenient for neutron shielding. Radium-beryllium sources of neutrons containing up to 100 mCi of radium do not require shielding beyond that provided for gamma radiation. Above 100 mCi, additional hydrogenous or other neutron-shielding material will usually be needed. (See ICRP Publication 4—Report of Committee IV on Protection Against Electromagnetic Radiation above 3 MeV and Electrons, Neutrons and Protons.)

CONTAMINATION CONTROL

(104) Unsealed radionuclides should be stored in tightly closed vessels except where chemical, radiation, or other action may produce undesirable gas pressures within the containers. Containers for solutions that produce significant quantities of gases should be properly vented and stored in a ventilated area. In many cases, a properly designed fume hood will be suitable for the storage of such material.

(105) Periodic surveys should be made around the storage area to determine external radiation levels and to detect unsuspected contamination.

FLOODING, FIRE AND THEFT

(106) The storage area and the design of the store should be so chosen as to minimize the hazards arising from flooding.

(107) When the amounts of radioactive materials in the store exceed prescribed or hazardous levels (for example 10 mCi of the more hazardous materials) the store should, as far as practicable, be fire resistant. The local fire department should be notified of such stores.

(108) Radioactive sources should be secured against unauthorized removal. Any loss or theft of radioactive material that may constitute a potential public health hazard should be reported to the police and public health authorities.

TRANSPORTATION OF RADIOACTIVE MATERIALS

TRANSPORTATION WITHIN AN ESTABLISHMENT

(109) The radiation protection officer should specify or approve the precautions to be taken for the movement of radioactive materials from one area to another within an establishment.

TRANSPORTATION OUTSIDE AN ESTABLISHMENT

(110) For transport outside the establishment, unless the carrier makes special arrangements to treat his employees as persons directly engaged in radiation work (as will often be the case in transport between nuclear energy establishments), they should be regarded as being persons not directly engaged in radiation work (see paragraph 3 and second footnote on page 1). It will be the responsibility of the carrier to control the transport of radioactive materials and the radiation exposure of his employees.

(111) Regulations drawn up by national authorities should ensure that the above provisions are satisfied, and should include specifications for packaging and permissible radiations from packages.*

(112) Provision should be made by national authorities for establishing procedures which can be followed in the event of accidents involving shipment of radioactive materials.

DISCHARGE OF HOSPITAL PATIENTS DURING TREATMENT WITH RADIOACTIVE MATERIALS

(113) National authorities may wish to give guidance about the conditions under which both in-patients and out-patients who are undergoing treatment with radioactive materials may be allowed to leave hospital to return to their homes. The maximum amounts of various radionuclides which can be permitted in a discharged patient will depend upon whether the patient travels by public transport or by ambulance or private car and upon considerations of radiation exposure of persons, particularly children, or unprocessed photographic films in proximity to the patient.

* Detailed guidance is given in "Regulations for the Safe Transport of Radioactive Materials" and in "Notes on Certain Aspects of the Regulations" International Atomic Energy Agency Safety Series Nos. 6 and 7, 1961.

(114) Estimates indicate that, on the assumption that the chance of any member of the public becoming closely involved with more than one radioactive patient is very small and that the journey time by public transport is 1 hr, the maximum activities are about 30 mCi of P-32 or of sealed Y-90 or Au-198, 15 mCi of I-131, 10 mCi of colloidal Y-90 or Au-198, and 12 mCi of sealed Rn-222.

(115) At the activities mentioned in paragraph 114, no unacceptable hazards will arise in the patient's home provided he does not come into close contact with young children. The latter restriction may be removed when the activities have fallen below one-quarter of the maxima.

DISPOSAL OF RADIOACTIVE CORPSES*

(116) Precautions should be taken to ensure that corpses containing radioactive materials will not be hazardous to pathologists or undertakers or to those who carry out embalming or cremating. The radiation safety officer of the hospital at which treatment with radioactive materials was carried out should be consulted on the radiation problems associated with any post-mortem procedures or disposal of corpses.

(117) No special precautions are necessary for post-mortem examinations outside treatment centres or the embalming of corpses containing not more than 5 mCi of Rn-222 or of colloidal Y-90 or Au-198, 10 mCi of P-32, or 15 mCi of I-131 or of sealed Y-90 or Au-198.

(118) The quantities given in paragraph 117 are not necessarily applicable to post-mortem examinations at the treatment centre since the cases may be more frequent.

(119) Embalming of corpses containing greater quantities than those specified in paragraph 117 should not normally be carried out. Where special reasons for embalming are advanced in any particular case, the radiation protection officer of the hospital concerned should be consulted.

(120) No special precautions are necessary in the case of cremation of corpses containing up to 30 mCi of Y-90, I-131, Au-198, or Rn-222 or 10 mCi of P-32.

(121) Temporary implants of isotopes should, where necessary, be removed from corpses before their release from hospitals.

(122) If the activity of a live patient on discharge from hospital exceeds the values given in paragraph 117, the hospital authorities should indicate to the patient's family doctor the date before which, in the event of the death of the patient, no post-mortem examination or embalming or cremation should be performed without reference to them.

* For further details the reader is referred to the U.S. Department of Commerce National Bureau of Standards Handbook 65—"Safe Handling of Bodies Containing Radioactive Isotopes", 1958.

APPENDICES

APPENDIX A

METHODS OF TESTING SEALED SOURCES FOR LEAKAGE OF SURFACE CONTAMINATION

(A.1) A number of methods may be used for testing the leakage or surface contamination of sealed sources or of teletherapy-type γ -ray beam units containing sealed capsules. The following examples are given for guidance.

(A.2) The entire external surface of a sealed source should be wiped with material (e.g. filter paper) moistened with a liquid which is effective in removing the radioactive material involved and which does not attack the container or any bonding material. If the test indicates that the amount of free activity on the surface of the container is less than $0.05 \mu\text{Ci}$, the container may be considered to be free from leakage.

(This method is not applicable in the case of sources of very small dimensions, whilst in the case of teletherapy equipment, which houses source capsules of high activity, it may not be practicable to wipe its entire surface but only a portion of it, e.g. inside the beam collimator. A different criterion for the assumption of leakage may then have to be adopted.)

(A.3) The source should be immersed in a liquid which will not attack the material of the container or bonding and which, under the conditions of this test, has been demonstrated to be effective in removing the radioactive material involved. The liquid should be heated to $50 \pm 5^\circ\text{C}$ and held at this temperature for 8 hr. If the activity of the liquid is then less than $0.05 \mu\text{Ci}$, the source may be considered to be free from surface contamination.

(A.4) The source should be immersed in a suitable liquid and the pressure on the surface of the liquid reduced to 100 mm mercury for a period of 30 sec. If no stream of fine bubbles appears from the source, the source may be considered to be free from leakage.

APPENDIX B

STERILIZATION OF SMALL SEALED SOURCES

(B.1) The following are given as examples of satisfactory ways of sterilizing small sealed sources. Wherever practicable, sterilizers should be adequately screened by protective material. They should, where necessary, be provided with means of preventing sources from being lost, for example, down drains.

(B.2.) *Boiling*

The design of the sterilizer should ensure that the temperature cannot rise about 110°C , even in the event of its boiling dry.

(B.3.) *Chemical*

Sources should be immersed for an appropriate period of time in a sterilizing solution which does not attack the material of the container.

(B.4.) *Hot-air*

In some cases, for example, gold grains in magazines, sterilization by hot air is effective.

APPENDIX C

DESCRIPTION OF TYPE 2 LABORATORY (INTERMEDIATE-LEVEL FACILITY)

(C.1) The following description of a Type 2 laboratory is intended as a guide to the various factors to be considered and is not intended as a recommendation. Circumstances will govern the facilities that will have to be provided in each individual case.

ROOMS

(C.2) Special rooms should be set aside for radioisotope work. If space permits, it is advisable to separate the laboratory from other space by a vestibule. In the vestibule can be kept special clothing, shoes, personnel monitoring devices, cleaning equipment, and washing facilities. Sources should not be stored in the vestibule. The vestibule should be separated from the laboratory by a barrier, which serves to draw attention to the presence of an active area.

(C.3) Depending upon the size of the installation under consideration, separate rooms or areas may be provided for storage of radionuclides, "hot" laboratories, storage of waste materials, chemical laboratories and particularly, in the case of hospitals, for an administrative room, clinical measurements room, and auto-radiography facilities.

In the average hospital laboratory for the therapeutic and diagnostic applications of radionuclides, space should be provided for :

- (a) isotope dispensary and stores ;
- (b) wash-up room ;
- (c) excreta and specimen store, with measurement facilities and sluice room ;
- (d) isotope surgery ;
- (e) clinical examination room ;
- (f) laboratories (clinical, bio-chemical, counting, etc.) ;
- (g) decontamination space.

Whilst separate rooms for the above functions are desirable, (a) and (b), and (d) and (e) may be combined, if relatively small activities are being used.

VENTILATION

(C.4) The ventilation of the laboratory should be such that air from it cannot pass to other parts of the building. If air conditioning is required, the system should be such that air from fume hoods or closed boxes cannot be drawn into the ventilation system of the building.

(C.5) There should be a fume hood designed to provide a smooth flow of air and to avoid eddy currents, and the air flow into the laboratory should be sufficient to replace that which is exhausted through the fume hood.

(C.6) The exhaust stack should proceed as directly as possible to the roof of the building. It should not be connected with any nonradioactive system, and the exit should be located above the uppermost part of the building. The motor providing the air flow should be placed close to the exit, in order to produce a negative pressure in as long a length of the stack as possible. Although it is not always necessary, it may be advisable to install an absolute filter* near the junction of hood and ventilation duct stack. If a filter is installed, it should be so situated that it can be monitored and changed easily.

(C.7) The inside of the fume hood should have an easily cleaned surface. Gas, air, water and electrical outlets should be controlled from outside the hood. It is advisable to install lights outside of the hood, the light passing through a glass panel. The illuminating unit can thus be changed without having to enter the hood.

(C.8) If gamma-emitting nuclides are to be used in the hood, provision should be made for supporting the weight of the shielding. It should be remembered that shielding may be required above, below and behind the assembly, as well as to the sides and front.

WALL SURFACES

(C.9) The walls and ceilings should be covered with a hard nonporous washable paint. The floors should be covered with impermeable materials such as linoleum or plastic tile, treated with a layer of wax. The junction of floor and wall should be rounded for easy cleaning.

* An absolute filter is one which removes 99.97 per cent of particles 0.02 micron in diameter.

FURNITURE

(C.10) The furniture should be kept to a minimum and should be constructed of material that is easily cleaned. Bench surfaces should be covered with impermeable materials such as laminated plastic, stainless steel, or linoleum.

PLUMBING

(C.11) It is advisable to install a sink in a fume hood for the primary wash of very active glassware. There should also be at least one large wash-up sink equipped preferably with remote action taps (knee, elbow, or foot) for cleaning glassware. The drain should proceed as directly as possible to a main sewer, and the trap should be accessible for periodic monitoring. There should be sufficient flow in this system to provide adequate dilution of any radioactive waste released.

(C.12) Ordinary porcelain sinks are satisfactory, provided the bottom of the sink slopes slightly toward the drainage plug.

WASTE CONTAINERS

(C.13) This section will deal only with the equipment necessary for collecting dry and liquid waste.

(C.14) To avoid accumulation of waste in the working area, it is advisable to have a system of collection and transfer to storage or disposal. Several types of containers should be available; cans with foot-operated lids and provided with non-porous bags are suitable for immediate disposal of solid waste. Larger cans with lids are useful for temporary storage and also for carrying material out for final disposal. Any can that would be removed from the laboratory should be clearly, distinctively marked with an appropriate symbol.

(C.15) Liquid waste that is too active for disposal through the drains should be collected in containers. It may be advisable to connect two of these in series in order to provide for the possibility of overflow.

SPECIAL EQUIPMENT

(C.16) Special equipment, suitable for the type and level of activity being used, should be provided for each type of operation. This should include local shielding, trays, and handling tools, such as tongs, forceps, and mechanical holders. Long-handled tools and local shielding provide adequate protection where millicurie amounts of beta or gamma activity are encountered. Operations with larger amounts of radioactive materials require the use of specially designed, remote-controlled equipment, including a shielded optical system (e.g. a periscope or mirror arrangement). When the nuclides concerned are primarily beta emitters, efficient use can be made of transparent plastic shields fitting closely around the equipment to allow handling with good visibility. Containers for active material should incorporate the necessary shielding as close to the source as possible. Containers for liquid samples should always be protected by an outer, unbreakable container. (See also Section on "Disposal of Radioactive Wastes").

(C.17) Glassware used in the radionuclide laboratory should be reserved for that purpose and should be suitably marked.

(C.18) Equipment should be provided for remote pipetting of liquid; this should never be done by mouth. For low-level work, simple hand bulb or syringe pipettes are adequate, but more elaborate, remote-controlled devices are necessary for intermediate and high level work.

(C.19) When several sealed gamma-emitting sources are used, it may be advisable to provide a lead-lined safe with lead-filled trays. This permits the individual sources to be stored in holes in the tray. Separate compartments should be provided for different types of sources. Each compartment should be marked so as to permit immediate and certain identification of its contents from the outside. It is highly desirable that tubes, cells, needles, etc., be readily identifiable from a considerable distance as to their type and activity.

APPENDIX D
RADIOACTIVE CONTAMINATION OF SURFACES

(D.1) It is impossible to express a quantitative relationship between the levels of radioactivity on various surfaces and the resulting radiation doses to personnel. Actual doses of radiation, particularly as a result of inhalation and ingestion, will depend upon the nature of the radioactive material, upon working conditions, upon the personal habits of the worker, and upon the fractions of "free" and "fixed" radioactive material. In practice, limits which various laboratories have

TABLE D.1. EXAMPLES OF PRESCRIBED VALUES OF SURFACE CONTAMINATION

Site	NCRP Handbook 48	British Codes of Practice	Atomic Energy of Canada Ltd. (c)	France CEA
		(in $\mu\text{Ci}/\text{cm}^2$)	(in $\mu\text{Ci}/\text{cm}^2$)	(in $\mu\text{Ci}/\text{cm}^2$)
1. Hands and other parts	0.1 mrep/hr (a) 1.0 mrep/hr (b)	$\alpha 10^{-5}$ $\beta 10^{-4}$	$\alpha 10^{-6}$ $\beta 10^{-4}$	$\alpha 5 \times 10^{-6}$ (a) $\beta 5 \times 10^{-5}$ (a) $\beta 5 \times 10^{-5}$ (b)
2. Personal clothing	Same as above	$\alpha 10^{-5}$ (a) $\alpha 10^{-4}$ (b) $\beta 10^{-4}$	$\alpha 10^{-6}$ $\beta 5 \times 10^{-4}$	$\alpha 10^{-5}$ (a) $\beta 10^{-4}$ (a) $\beta 10^{-4}$ (b)
3. Protective clothing, glassware, tools, objects to be handled with bare hands	Same as above	$\alpha 10^{-4}$ (a) $\alpha 10^{-3}$ (b) $\beta 10^{-3}$	$\alpha 10^{-6}$ $\beta 10^{-3}$	$\alpha 10^{-4}$ (a) $\beta 10^{-3}$ (a) $\beta 10^{-3}$ (b)
4. Active areas	Same as above	Same as above	$\alpha 10^{-5}$ β "clean on swipe". Less than 2 mR/hr on contact	Same as above
5. "Inactive" areas	Same as above	$\alpha 10^{-5}$ (a) $\alpha 10^{-4}$ (b) $\beta 10^{-4}$	$\alpha 10^{-6}$ $\beta 10^{-5}$	$\alpha 10^{-5}$ (a) $\beta 10^{-4}$ (a) $\beta 10^{-4}$ (b)

(a) Very hazardous radionuclides { In NCRP Handbook 92, the level for radionuclides corresponding to Groups 1 and 2 of Table 1, of the present Report, is given as 0.1 mrad/hr whilst that for radionuclides corresponding to Groups 3 and 4 of Table 1 is given as 1.0 mrad/hr.
 (b) Other radionuclides {
 (c) The fundamental test is that the surface must be "clean on swipe", and "swipe" tests cannot be expressed as $\mu\text{Ci}/\text{cm}^2$. The background in the active areas is such that $10^{-4} \mu\text{Ci}/\text{cm}^2 \beta$ could not be measured with the instruments available. With these provisos, the nearest values that could be indicated that conform with the others listed are those shown in this column.

found to be desirable are generally lower than those which might be expected to result in a substantial contribution to the total radiation dose which may be received under recommended permissible levels. This is because they are based on technical considerations such as the desirability of minimizing transfer of radioactivity from one area to another, the necessity for low radiation background in the use of certain instruments, and the limits of sensitivity of instrumentation used in the detection of surface concentrations, or on the administrative desirability of minimizing the

need for special precautions to avoid personal contamination with radioactivity while working in laboratory areas. While the importance of these considerations will vary from one operation to another, some initial guidance in the planning of laboratory operations will be afforded by the summary, given in Tables D.1. and D.2. of this Appendix, of surface concentrations used or suggested by various groups.

TABLE D.2. PRESCRIBED VALUES OF SURFACE CONTAMINATION
(OAK RIDGE NATIONAL LABORATORY)

Site	Method	Contamination value
Skin—hands	Direct reading	α 150 d.p.m. per 100 cm ² , or 6.7×10^{-7} μ Ci/cm ² β - γ 0.3 mrad/hr
Skin—general body	Direct reading	α 150 d.p.m. per 100 cm ² , or 6.7×10^{-7} μ Ci/cm ² β - γ 0.06 mrad/hr
Clothing (other than contaminated zone)	Direct reading	α 150 d.p.m. per 100 cm ² , or 6.7×10^{-7} μ Ci/cm ² β - γ 0.25 mrad/hr
Clothing (contaminated zone)	Direct reading	α 150 d.p.m. per 100 cm ² , or 6.7×10^{-7} μ Ci/cm ² β - γ 0.75 mrad/hr
Non-contamination zone areas	Direct reading	α 300 d.p.m. per 100 cm ² , or 1.3×10^{-6} μ Ci/cm ² β - γ 0.25 mrad/hr
	Transferable (smear survey)	α 30 d.p.m. per 100 cm ² , or 1.3×10^{-7} μ Ci/cm ² β - γ 1000 d.p.m. per 100 cm ² , or 4.5×10^{-6} μ Ci/cm ²
Tools and equipment for re-issue	Direct reading	α 300 d.p.m. per 100 cm ² , or 1.3×10^{-6} μ Ci/cm ² β - γ 0.05 mrad/hr
	Transferable (smear survey)	α 30 d.p.m. per 100 cm ² , or 1.3×10^{-7} μ Ci/cm ² β - γ 200 d.p.m. per 100 cm ² , or 9×10^{-7} μ Ci/cm ²

(D.2) It should be noted that actual surface contamination of radioactivity corresponding to the various specified "limits" listed in Tables D.1. and D.2. may depend heavily upon instrumentation and techniques not described. As a result, two laboratories using the same nominal limits may differ substantially in actual surface concentrations permitted. Although, at the time the limits were specified, no indications were given about the fractions of "free" and "fixed" contamination, it is presumed that the limits refer to the "free" component. The limits for the "fixed" component would be dictated by considerations of the amount of external radiation likely to be received by personnel.

(D.3) Values given in Tables D.1. and D.2. are frequently estimated from measurements of a physical quantity different from that stated in the tables. For example, a garment may be moni-

tored for radioactivity by placing it in a fixed geometrical relationship to a network of G-M tubes counting in parallel. The corresponding response of the counters depends not only on the total radioactivity on the garment but upon the quality of radiation and upon the distribution of the radioactivity relative to the counters. While an average dose rate, corresponding to the observed counting rate, may be determined approximately by substitution of a uniformly distributed and calibrated source of beta radiation for the garment and observing the corresponding counting rate, in any particular measurement actual dose levels made at various locations on the surface of the garment may be greatly different from that indicated by the "calibration".

(D.4) For some of the levels of surface concentration listed in the tables, some care in the choice of instruments may be required. Most alpha emitters are calibrated to read in disintegrations or counts per minute which can be related to the $\mu\text{Ci}/\text{cm}^2$ of the area in which contamination is detected. Gamma survey instruments are generally calibrated in mR/hr which can be related to curie units. In the case of the beta dose, the standard procedure is to read the beta dose in mR/hr on a gamma calibrated instrument. Since a beta-gamma detector will record nearly all beta activity reaching the sensitive element, a crude estimate of the activity can be obtained in counts per minute. (For example, for many G-M tubes, a reading of 0.2 mR/hr is approximately equivalent to 600 counts per minute.)

(D.5) A maximum level of 1 mR/hr average, as measured in a small volume of air (in a thin layer) above the surface of the body, if due to a gamma-emitting radionuclide, corresponds very approximately to a reading of about 1 000 counts per minute when a Geiger counter (with a flat plate area of 2 in² or 12 cm²) is placed as close as possible to the contaminated area. The actual value will depend on the energy of the radiation, self-shielding, and the relative amounts of beta and gamma radiation present. Levels of contamination of the most hazardous radionuclides should not give rise to dose rates exceeding 0.1 mR/hr (or about 100 counts per minute).*

APPENDIX E

EXAMPLE OF A PROCEDURE FOR DEALING WITH A SERIOUS SPILL

E.1. IMMEDIATE EMERGENCY ACTION

Until a plan has been worked out for decontaminating the area affected by a serious spill, only the minimum emergency action should be taken :

- (a) Evacuate all non-essential staff and, if necessary, patients, ensuring that no person from the affected area proceeds far into the inactive area until he has been monitored and found free from dangerous contamination. (This does not apply to injured personnel, but, if possible, their protective clothing should be left in the laboratory) ;
- (b) if a spill has occurred on skin, flush the skin thoroughly with water ;
- (c) remove affected clothing and leave it in the contaminated room if spill is on clothing ;
- (d) stop all operations, which, if continued, would add to the contamination ;
- (e) notify the radiation safety officer and the head of the department ;
- (f) post a danger notice to warn others not to enter the contaminated area inadvertently ; and
- (g) decontaminate persons involved in the spill while these emergency measures are being carried out. If normal washing procedures do not suffice to reduce contamination below the required level (Appendix D), the cases should be referred to the medical adviser.

The order in which these operations should be done will vary with circumstances ; in many cases several will be conducted simultaneously.

* See also National Bureau of Standards Handbook 92—"Safe Handling of Radioactive Materials", March 9 1964.

E.2. ACTION WHEN IMMEDIATE EMERGENCY IS OVER

- (a) Before re-entering the affected area to carry out decontamination measures, the personnel involved should wear suitable protective clothing (including gloves, footwear, respirators) according to the seriousness of the accident. These persons should be submitted to the normal monitoring procedures (external and internal radiation) and decontaminating procedures.
- (b) Re-entry of other persons to the affected area should be restricted until radiation surveys have indicated that it is safe to do so.
- (c) In some instances it may be necessary to carry out tests on persons involved in the accident to determine the amount of radioactive material that has entered the body.
- (d) If any person involved in an emergency has been grossly over-exposed to external radiation and has been found to have an unduly high amount of radioactive material in his body or an open wound, the medical adviser should arrange for remedial treatment to be given.

APPENDIX F

MANAGEMENT OF RADIOACTIVE WASTES

GENERAL PRINCIPLES

(F.1) Radioactive wastes are an inevitable result of the use of radioactive materials and of other nuclear energy operations. Reduction of radioactivity occurs only as a result of nuclear changes at rates which cannot be altered. It is, therefore, necessary to manage these materials in such a manner that, while their radioactivity is decaying to negligible amounts, there will be no excessive exposure of persons to radiation.

(F.2) There are two principal ways in which this objective can be achieved. In the first method, most of the radioactive material in the waste is stored under controlled conditions, either permanently or until it has decayed to levels which permit it to be dealt with by disposal. By the second method, the radioactivity is disposed into man's surroundings in such a way that natural processes do not transfer it back to man in amounts or concentrations sufficient, in combination with other sources of radiation, to cause exposure greater than the maximum permissible doses recommended by the Commission. In some cases, a combination of these methods is used, as when a waste is treated so that part of the radioactivity is concentrated and stored while the remainder is discharged into the environment as a partially purified waste.

(F.3) In selecting the most appropriate method of disposal, it is necessary to estimate the likely radiation doses both to workers dealing with the waste and to members of the public. These estimated doses must be below the maximum permissible doses recommended by the Commission. In many cases, several methods of disposal will comply with this requirement and, in making a selection, a number of other considerations should be taken into account:

(a) the Commission's advice to keep all doses as low as practicable; (b) any other radiological or non-radiological risks which may be associated with the handling, storage, or dispersal of the waste; and (c) the comparative costs of the available methods and the extent to which doses may be reduced, in relation to the maximum permissible doses, by increased expenditure.

(F.4) Although the exercise of this selection will necessarily involve a skilled judgement, the decision in the case of wastes from hospitals and medical research establishments will often be straightforward. In such cases, the amount of radioactive material in the waste is such that any of the disposal methods under consideration will give rise to doses which are small in comparison with recommendations of the Commission and considerations (b) and (c) will then predominate. More complex situations will arise in the case of wastes from atomic energy installations, but these are outside the scope of this report.

(F.5) In planning the disposal of radioactive waste from any establishment, it is necessary to consider each type of waste separately, but to remember that they may jointly result in exposure of the same individuals. It is also necessary to plan, as far as practicable, for future developments which may alter the nature or amounts of the waste.

(F.6) Certain types of releases may combine, in some degree, factors of retention and dispersal. For example, burial in the ground ensures that the material is released so slowly that it will be widely dispersed, and thus, depending upon the half-lives of the radionuclides involved, may greatly reduce the quantity of radioactive materials to which people are exposed.

(F.7) Waste materials may be gases, liquids, or solids. They may be carried as aerosols, as suspensions in water, or as solutions. Materials commonly regarded as insoluble may not be insoluble in waters of various chemical composition. The concentrations of radioactive materials in air, water and food supplies will depend upon such factors as dilution and migration in the environment and uptake by plants and animals. These factors depend, in turn, upon the physical and chemical characteristics of the local terrain, upon local meteorological and hydrological conditions, upon utilization by plants and animals, and upon relative locations of population groups. Thus, procedures for the release of large quantities of radioactive wastes to the environment should be considered in relation to local circumstances which often call for specialized knowledge in many fields.

DISPOSAL OF LIQUID WASTES

(F.8) It is often convenient and practicable to dispose of small quantities of soluble radioactive wastes, containing nuclides of short half-lives, into the sanitary sewerage system. This procedure provides a period of delay for decay before the radioactive materials can reach water or food supplies, and provides some degree of dispersal and dilution. For several of the more commonly used radionuclides, release into the sanitary sewerage system also provides mixing with non-radioactive isotopes of the same chemical elements, which may considerably reduce uptake by plants and animals. The results are, of course, dependent upon a number of factors such as the size of the sewerage system, methods of handling sewage, utilisation of effluent after sewage treatment, and the chemical properties of the radioactive materials involved.

(F.9) Direct discharge into the sanitary sewerage system is particularly satisfactory for the disposal of excreta from patients given radioactive materials in medical diagnosis and therapy. The relationships between quantities of radioactivity releases, radioactive half-lives, and quantities of sewage handled by the system will usually be such as to require no special precautions other than those which may be necessary to protect plumbers and sewage workers near points of discharge. If no piped sewerage system exists, the responsible authorities will have to evaluate the method of discharge in terms of potential exposure to people.

(F.10) It is possible to give a range of permissible concentrations of radionuclides in the effluent from an establishment (see paragraph 90) which will usually be sufficient to allow disposal of the wastes which arise. Even with more active wastes, release to the sewerage system may be acceptable, for example, if the system does not discharge to a potential source of drinking water. On the other hand, some uses of water (e.g. for agriculture and industry) may require even lower concentrations of radionuclides than does use for drinking water. In such cases, the concentration of radioactivity in the receiving water should also be considered and related to the uses of the water.

(F.11) The responsibility for supervision of practices involving the release of radioactive materials into the environment will vary from one country to another but competent authorities should ensure that the sum total of all such releases will not result in excessive exposures.

DISPOSAL OF SOLID WASTES

(F.12) Low-level solid wastes may be disposed of with ordinary refuse (see paragraph 92). For larger amounts other methods of disposal, including incineration or burial, may be used.

(F.13) When a nuclide is not volatile, it will concentrate in the ash. Hazards from the ash will arise during removal and final disposal, usually as landfill. Probably the limiting hazard during removal will be that due to inhalation of the ash. This hazard can be evaluated in terms of maximum permissible concentrations in the refuse accepted for incineration by a study of the time taken by the removal operation and the maximum permissible concentrations for air. In a similar way, the inhalation hazard arising from dumping on land should be evaluated.

(F.14) Apart from the waste arising from the normal operations and spills, wastes also arise from accidents in poor conditions of working. Accidents will occur occasionally despite all precautions, but wastes from poor working conditions need never arise.

(F.15) The most troublesome in the category of "abnormal wastes" is probably that which occurs when rooms and sometimes whole buildings become contaminated due to the careless or reckless spread of radioactive materials. Despite decontamination procedures, it may be necessary to strip the room or even to demolish the building.

(F.16) While the room may be unsuitable for laboratory work because of high levels of radiation, it may, when broken up into rubble or disposed of by burial, not contribute significantly to the general background radiation. No general rules can be formulated and each disposal should be considered individually.

DISPOSAL OF AIRBORNE WASTES

(F.17) When gaseous radioactive wastes are routinely discharged to the environment, some evaluation of the local conditions will be necessary to determine permissible amounts of disposal. Decisions can then be made regarding the heights of any stacks or the need to equip ventilation systems with filters. Where large quantities of radionuclides are discharged to the atmosphere, it is advisable to prove the adequacy of the disposal system by carrying out regular monitoring or environmental surveys, since many radionuclides will be concentrated by absorption on surfaces. For example, iodine-131 settles out on grass, is taken up by grazing cattle, and is secreted into the cow's milk. This biological concentration sets a permissible level in air over pasture land much lower than the maximum permissible concentration set for air on the basis of inhalation, usually about one ten-thousandth of the latter.

STORAGE OF WASTES

(F.18) Procedures for the storage of radioactive wastes depend upon many factors. Some of the more obvious ones are quantities, concentrations, and radioactive half-lives; feasibility and cost of engineering processes; reliability of storage containers; and availability of suitable storage sites. Radioactive half-lives are of particular importance. In some cases, retention of the waste for a few days may suffice; in others, storage may be required for very long periods before the radioactivity decreases to levels permitting release to the environment. Special facilities should be provided for such prolonged storage.

(F.19) Containment may be preceded by concentration. Here the waste is reduced to the smallest practicable bulk for storage in suitable facilities. The methods of concentration may include evaporation, chemical precipitation, solvent extraction, and ion exchange. In the case of combustible solid wastes, concentration in incinerators of proper design may be practicable. Alternatively, baling of combustible material can be used to reduce spatial requirements for above ground storage or burial. With all such methods, secondary low activity waste may be released into the environment.

RECOMMENDATIONS OF THE INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION

ORGANIZATION

THE International Commission on Radiological Protection originated in the Second International Congress of Radiology in 1928. Since then the Commission has had a close relationship with succeeding Congresses, and it has also been looked to as the appropriate body to give general guidance on the more widespread use of radiation sources caused by the rapid developments in the field of nuclear energy. The Commission wishes to maintain fully its traditional contact with medical radiology, and to fulfil its responsibilities to the medical profession. In addition, the Commission recognizes its responsibility to other professional groups and its obligation to provide guidance within the field of radiation protection as a whole.

The policy adopted by the Commission in preparing its recommendations is to deal with the basic principles of radiation protection, and to leave to the various national protection committees the responsibility of introducing the detailed technical regulations, recommendations, or codes of practice best suited to the needs of their individual countries.

The Commission has kept its recommendations continually under review in order to cover the increasing number and scope of potential radiation hazards, and to amend safety factors in the light of new knowledge concerning the effects of ionizing radiations.

Since the Ninth International Congress of Radiology in Munich the Commission has published two reports, entitled "Permissible Dose for Internal Radiation" (ICRP Publication 2), and "Protection Against X-rays up to Energies of 3 MeV and Beta- and Gamma-rays from Sealed Sources" (ICRP Publication 3). The latter report is essentially a code of practice for medical radiologists.

In 1959 the International Commission on Radiological Protection and the International Commission on Radiological Units and Measurements were jointly asked by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) to prepare a report dealing with somatic effects of medical radiation exposures. A study group was appointed at the Munich meeting; it met in 1960, and prepared a report entitled "Exposure of Man to Ionizing Radiation Arising from Medical Procedures, with Special Reference to Radiation-Induced Diseases". The report was submitted to the UNSCEAR at the end of 1960, and in 1961 it was published in *Physics in Medicine and Biology* 6, No. 2 (Taylor & Francis Ltd., London).

Committee reports have also been prepared on :

- (a) Protection Against Electromagnetic Radiation above 3 MeV and Electrons, Neutron and Protons ;
- (b) Handling and Disposal of Radioactive Materials in Hospitals and Small Establishments ;
- (c) RBE (Relative Biological Effectiveness).*

It is expected that these reports will be published during 1964.

The Commission has maintained close contact with the World Health Organization (WHO) and with the International Atomic Energy Agency (IAEA), with both of which the Commission has an official relationship. The Commission has been represented by observers at a number of meetings organized by the WHO and the IAEA. Co-operation has also been maintained with the International Labour Office (ILO), the Food and Agriculture Organization, and the UNSCEAR,

* Published in *Health Physics* 9, No. 4 (1963).

all of which have been invited to send observers to technical meetings of the Commission and its committees. The Commission has been represented at all meetings of the UNSCEAR during the period 1960–1962.

During the period between the two last Congresses, the ILO has prepared an international instrument consisting of a Radiation Protection Convention (No. 115) supplemented by a Recommendation (No. 114). The Commission realizes that the reference to its work, in paragraphs 3, 4 and 5 of the Recommendation, increases its responsibility and adds to the importance of keeping its recommendations continually under review.

Grants of money have been made to the Commission by a number of organizations. The Ford Foundation has allocated \$250,000, to be paid over a period of 5 years. The World Health Organization contributed \$9,000 in the years 1960 and 1961, and \$10,000 in 1962 and 1963. The International Society of Radiology gave \$3,000 for the period between the 1959 and 1962 Congresses and \$3,000 for 1963. A sum of \$10,000 was received from the UNSCEAR in connection with the work of the Joint Study Group described above. The International Atomic Energy Agency has contributed \$6,000 for 1963. The Commission wishes to express its sincere appreciation to all these organizations.

A meeting of the Commission and its committees was held in Stockholm in May 1962. The Commission also met in Ottawa in executive sessions immediately before the Tenth International Congress of Radiology; at these meetings the Commission prepared the present report incorporating its latest recommendations as well as amendments to previous recommendations.

Since the meeting in Munich the Commission has suffered the death of two of its most distinguished members; its Chairman Emeritus, Sir Ernest Rock Carling, and its Vice-Chairman Emeritus, Professor G. Failla. The Commission owes a great debt of gratitude to them for their invaluable work during the most significant years in the history of radiation protection.

During the preparation of this statement the ICRP has had the following composition :

1959–1962

R. M. SIEVERT, <i>Chairman</i> (Sweden)	J. F. LOUTIT (Great Britain)
E. E. POCHIN, <i>Vice-Chairman</i> (Great Britain)	K. Z. MORGAN (U.S.A.)
W. BINKS (Great Britain)	H. J. MULLER (U.S.A.)
L. BUGNARD (France)	R. S. STONE (U.S.A.)
H. HOLTHUSEN (Germany)	L. S. TAYLOR (U.S.A.)
J. C. JACOBSEN (Denmark)	E. A. WATKINSON (Canada)
R. G. JAEGER (Germany)	

SIR ERNEST ROCK CARLING, *Chairman Emeritus* (Great Britain)—Deceased 1960

G. FAILLA, *Vice-Chairman Emeritus* (U.S.A.)—Deceased 1961

B. LINDELL, *Secretary* (Sweden)

1962

E. E. POCHIN, <i>Chairman</i> (Great Britain)	K. Z. MORGAN (U.S.A.)
L. BUGNARD, <i>Vice-Chairman</i> (France)	H. J. MULLER (U.S.A.)
W. BINKS (Great Britain)	R. M. SIEVERT (Sweden)
O. HUG (Germany)	C. G. STEWART (Canada)
H. JAMMET (France)	R. S. STONE (U.S.A.)
B. LINDELL (Sweden)	L. S. TAYLOR (U.S.A.)
J. F. LOUTIT (Great Britain)	

F. D. SOWBY, *Scientific Secretary* (Canada)

During the Stockholm meeting in May, 1962, the Commission decided to reorganize the structure of its committees. The previous committees were dissolved at the time of the Tenth International Congress of Radiology and four new committees were established to review various topics of interest to the Commission :

1. Radiation Effects
2. Internal Exposure
3. External Exposure
4. Application of Recommendations.

The following have accepted invitations to serve as members of these committees :

Committee 1

J. F. LOUTIT, <i>Chairman</i> (Great Britain)	J. LEJEUNE (France)
F. DEVIK (Norway)	H. B. NEWCOMBE (Canada)
A. R. GOPAL-AYENGAR (India)	R. SCOTT RUSSELL (Great Britain)
O. HUG (Germany)	A. C. UPTON (U.S.A.)
L. F. LAMERTON (Great Britain)	

Committee 2

K. Z. MORGAN, <i>Chairman</i> (U.S.A.)	L. D. MARINELLI (U.S.A.)
W. BINKS (Great Britain)	W. G. MARLEY (Great Britain)
A. M. BRUES (U.S.A.)	E. E. POCHIN (Great Britain)
B. CHR. CHRISTENSEN (Denmark)	V. SHAMOV (U.S.S.R.)
M. IZAWA (Japan)	W. S. SNYDER (U.S.A.)
M. LAFUMA (France)	C. G. STEWART (Canada)

Committee 3

E. E. SMITH, <i>Chairman</i> (Great Britain)	A. PERUSSIA (Italy)
J. DUTREIX (France)	E. DALE TROUT (U.S.A.)
R. G. JAEGER (Austria)	B. M. WHEATLEY (Great Britain)
L.-E. LARSSON (Sweden)	H. O. WYCKOFF (U.S.A.)

Committee 4

H. JAMMET, <i>Chairman</i> (France)	D. MECHALI (France)
D. J. BENINSON (Argentina)	C. POLVANI (Italy)
G. C. BUTLER (Canada)	P. RECHT (Belgium)
H. DAW (U.A.R.)	C. P. STRAUB (U.S.A.)
H. J. DUNSTER (Great Britain)	E. G. STRUXNESS (U.S.A.)
B. LINDELL (Sweden)	F. WESTERN (U.S.A.)

This reorganization does not change, in essence, the scope of program of the previous Committees I and II, but the old Committees III, IV and V and the ICRP/ICRU Committee on RBE are not included as such under the new structure. All problems relating to external exposure, both for quantum and for particulate radiation at any energy, will now be considered within the new Committee 3. Special *ad hoc* task groups will be set up from time to time to deal with specific problems.

The Committees I-V and the *ad hoc* Committee on RBE had the following composition during the period 1959-1962.

Committee I (Advisory Committee on Biology)

J. F. LOUTIT, <i>Chairman</i> (Great Britain)	H. B. NEWCOMBE (Canada)
A. A. BUZZATI-TRAVERSO (Italy)	J. NIELSEN (Denmark)
J. A. COHEN (The Netherlands)	R. SCOTT RUSSELL (Great Britain)
F. DEVIK (Norway)	A. C. STEVENSON (Great Britain)
A. R. GOPAL-AYENGAR (India)	A. C. UPTON (U.S.A.)
L. F. LAMERTON (Great Britain)	S. WARREN (U.S.A.)
J. LEJEUNE (France)	

Committee II (Protection against radiation from internal radioactive substances)

K. Z. MORGAN, <i>Chairman</i> (U.S.A.)	L. D. MARINELLI (U.S.A.)
W. BINKS (Great Britain)	W. G. MARLEY (Great Britain)
A. M. BRUES (U.S.A.)	M. POBEDINSKI (U.S.S.R.)
B. CHR. CHRISTENSEN (Denmark)	E. E. POCHIN (Great Britain)
M. IZAWA (Japan)	W. S. SNYDER (U.S.A.)
W. H. LANGHAM (U.S.A.)	C. G. STEWART (Canada)

Committee III (Protection against X-rays and electrons up to energies of 3 MeV and beta- and gamma-rays from sealed sources)

R. G. JAEGER, <i>Chairman</i> (Germany)	L. LORENTZON (Sweden)
E. E. SMITH, <i>Vice-Chairman</i> (Great Britain)	S. B. OSBORN (Great Britain)
C. B. BRAESTRUP (U.S.A.)	C. POLVANI (Italy)
E. D. TROUT (U.S.A.)	D. J. STEVENS (Australia)
C. GARRETT (Canada)	H. O. WYCKOFF (U.S.A.)
F. GAUWERKY (Germany)	J. ZAKOVSKY (Austria)
H. HOLTHUSEN (Germany)	A. ZUPPINGER (Switzerland)

Committee IV (Protection against electrons and electromagnetic radiation above 3 MeV, neutrons and radiation from heavy particle accelerators)

G. J. NEARY, <i>Chairman</i> (Great Britain)	W. H. KOCH (U.S.A.)
J. W. BOAG (Great Britain)	J. S. LAUGHLIN (U.S.A.)
F. HERČÍK (Czechoslovakia)	C. A. TOBIAS (U.S.A.)
G. S. HURST (U.S.A.)	M. TUBIANA (France)
H. E. JOHNS (Canada)	B. M. WHEATLEY (Great Britain)
G. JOYET (Switzerland)	K. G. ZIMMER (Germany)

Committee V (Handling of radioactive isotopes and disposal of radioactive waste)

C. P. STRAUB, <i>Chairman</i> (U.S.A.)	A. A. PERUSSIA (Italy)
L. R. DONALDSON (U.S.A.)	E. H. QUIMBY (U.S.A.)
H. J. DUNSTER (Great Britain)	F. D. SOWBY (Canada)
H. JAMMET (France)	E. G. STRUXNESS (U.S.A.)
A. W. KENNY (Great Britain)	F. WESTERN (U.S.A.)
C. A. MAWSON (Canada)	

ICRP/ICRU Committee on RBE (Relative biological effectiveness)

L. F. LAMERTON, <i>Chairman</i> (Great Britain)	O. HUG (Germany)
J. F. LOUTIT (Great Britain)	H. I. KOHN (U.S.A.)
H. H. ROSSI (U.S.A.)	H. QUASTLER (U.S.A.)
W. S. SNYDER (U.S.A.)	M. TUBIANA (France)
G. J. NEARY (Great Britain)	A. C. UPTON (U.S.A.)

RULES GOVERNING THE SELECTION AND WORK OF THE INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION

1. (a) The International Commission on Radiological Protection (ICRP) shall be composed of a Chairman and not more than twelve other members. The selection of the members shall be made by the ICRP from nominations submitted to it by the National Delegations to the International Congress of Radiology and by the ICRP itself. The selections shall be subject to approval by the International Executive Committee (IEC) of the Congress. Members of the ICRP shall be chosen on the basis of their recognized activity in the fields of medical radiology, radiation protection, physics, health physics, biology, genetics, biochemistry and biophysics, with regard to an appropriate balance of expertise rather than to nationality.

(b) The membership of the ICRP shall be approved during each International Congress for service until the end of the succeeding Congress, or until new members are appointed. Not less than two but not more than four members shall be changed at any one Congress. In the intervening period vacancies may be filled by the ICRP.

(c) In the event of a member of the ICRP being unable to attend the ICRP meetings, a substitute may be selected by the ICRP as a temporary replacement. Such a substitute shall not have voting privileges unless specifically authorized by the ICRP.

(d) The ICRP shall be permitted to invite individuals to attend its meetings to give special technical advice. Such persons shall not have voting privileges, but their opinions may be recorded in the minutes.

2. The Chairman shall be elected by the ICRP from among its members to serve until the end of the succeeding Congress, or until his successor is elected. The choice shall not be limited to the country in which it is proposed to hold the succeeding Congress. The Chairman shall be responsible for reporting the proceedings and recommendations of the ICRP at the next Congress.

3. The ICRP shall elect from among its members a Vice-Chairman who will serve in the capacity of Chairman in the event that the Chairman is unable to perform his duties.

4. Minutes of meetings and records of the ICRP shall be made by a Scientific Secretary selected by the Chairman of the ICRP, subject to the approval of its members. The Scientific Secretary need not be a member of the ICRP. The records of the ICRP shall be passed on to the succeeding Scientific Secretary.

5. The Chairman, in consultation with the Vice-Chairman and the Scientific Secretary, shall prepare a program to be submitted to the Commission for discussion at its meetings. Proposals to be considered shall be submitted to the Chairman for circulation to all members of the ICRP and other specially qualified individuals at least two months before any meeting of the ICRP.

6. Decisions of the ICRP shall be made by a majority vote of the members. A minority opinion may be appended to the minutes of a meeting if so desired by any member, upon his submission of the same in writing to the Scientific Secretary.

7. The ICRP may establish such committees as it deems necessary to perform its functions.

RECOMMENDATIONS OF THE COMMISSION

A. PREFATORY REVIEW*

(1) Prior to the Geneva meeting of the Commission in April 1956, permissible levels of exposure to ionizing radiation had been expressed in terms of a dose in a rather short interval of time (1 day or 1 week), that is, essentially, in terms of an average dose-rate—the average referring to the temporal distribution of the dose in the specified interval of time. Implicitly, if not explicitly, it was assumed that if this average dose-rate was low enough, no appreciable bodily injury would become apparent in the lifetime of the individual. The assumption was based largely on radiological experience which indicated that substantial skin recovery occurred within a few months following a moderate therapeutic dose and that the latent period for some long-term effects of radiation (e.g. cancer of the skin) resulting from residual tissue damage, was longer the lower the dose (or dose-rate in the case of chronic exposure). Thus, in an occupationally exposed individual a long-term effect might not become apparent in his lifetime, even if a certain amount of permanent injury had occurred.

(2) The basic permissible weekly dose at that time was 0.3 rem/week. Assuming that a person was occupationally exposed at this rate (50 weeks a year) for 50 years, the permissible accumulated dose would be 750 rems in the most critical organs or essentially throughout the body. It was realized then that this constituted a "large" lifetime dose and an appropriate warning was included in the Commission's report of 1955.

(3) The general awareness of radiation hazards induced caution on the part of those responsible for the protection of workers. Administratively, liberal factors of safety were often used especially in large atomic energy installations. As a result it was found that in general the actual exposure of personnel was

kept at levels much below the then existing permissible limits.

(4) At the 1956 meeting of the Commission it became evident that stricter recommendations were needed. The 1955 Conference on the Peaceful Uses of Atomic Energy had aroused great interest in the development of atomic power plants throughout the world. In time this would greatly increase the number of persons occupationally exposed and would also bring about actual or potential exposure of other persons and the population as a whole. More importantly, the pressure for producing power economically might well do away with the "safety factors" mentioned above. Also, the average duration of occupational exposure per individual worker might increase. On the biological side it was considered that perhaps "recovery" plays a less important part in the long-term effects of radiation to be expected from continued exposure at low levels, than was earlier supposed. Because of the larger number of persons who would be exposed, occupationally or otherwise, genetic damage assumed greater importance. This was accentuated in no small degree by the realization that in some countries the per capita genetic dose contributed by medical procedures was about the same as that contributed by background radiation.

(5) Statistical studies had shown that the incidence of leukemia in radiologists was significantly greater than in other physicians who presumably were not professionally exposed to radiation. Of necessity these radiologists included those who had practiced their speciality at the time when radiation protection was not very effectively carried out. Therefore, the accumulated doses received by those who developed leukemia may have been much higher than the 750 rems mentioned above. On the other hand, since most of the exposure of these radiologists resulted from diagnostic

* Reproduced from the Commission's 1958 Recommendations. Footnotes added in 1962.

procedures carried out with low voltage X-rays, the lifetime dose in the blood-forming organs may have been lower than 750 rems even if the skin dose, especially in some parts of the body, was much higher. The mechanism of leukemia induction by radiation is not known. It may be postulated that if the dose is lower than a certain threshold value no leukemia is produced. In this case it would be necessary to estimate the threshold dose and to make allowances for recovery, if any. There is not sufficient information to do this, but caution would suggest that an accumulated dose of 750 rems might exceed the threshold. The most conservative approach would be to assume that there is no threshold and no recovery, in which case even low accumulated doses would induce leukemia in some susceptible individuals, and the incidence might be proportional to the accumulated dose. The same situation exists with respect to the induction of bone tumors by bone-seeking radioactive substances.

(6) Presently available longevity studies differ as to whether there is a statistically significant life shortening in radiologists as compared to other specialists presumably not occupationally exposed to radiation. However, in mammals chronically exposed at different daily doses a definite effect on longevity becomes clearly apparent at the higher daily doses. If extrapolation to lower daily doses, and then to man, is justified, it may be concluded that occupational exposure at presently accepted permissible limits may entail some life shortening. This effect may be interpreted as a slight acceleration of the natural aging process.

(7) The effects just discussed illustrate the two different types of possible long-term somatic effect that must be considered in setting up permissible limits of exposure. The first type (leukemia) is a serious effect occurring in some individuals and, therefore, the aim of protection would be to reduce the incidence to the lowest practical limit. The second type (life shortening) is presumably an effect on every individual and, therefore, the aim of protection would be to reduce the degree of effect to the lowest practical value. The definition of

permissible dose has been changed to include explicitly these two types of possible effect.

(8) Genetic effects manifest themselves in the descendants of exposed individuals. The injury, when it appears, may be of any degree of severity from inconspicuous to lethal. A slight injury will tend to occur in the descendants for many generations, whereas a severe injury will be eliminated rapidly through the early death of the individual carrying the defective gene. Thus the sum total of the effect caused by a defective gene until it is eliminated may be considered to be roughly the same. The main consideration in the control of genetic damage (apart from aspects of individual misfortune) is the burden to society in future generations imposed by an increase in the proportion of individuals with deleterious mutations. From this point of view it is immaterial in the long run whether the defective genes are introduced into the general pool by a few individuals who have received large doses of radiation, or by many individuals in whom smaller doses have produced correspondingly fewer mutations. However, even in this case it is desirable to limit the dose received by an individual.

(9) In view of the foregoing, recommendations are made in this report in terms of maximum permissible doses for individuals and for population groups. In either case limits are set on the basis of dose accumulated over a period of years rather than in terms of a weekly dose that could be received for an indefinite period of time. The concept of limiting the accumulated dose was introduced by the Commission at its 1956 meeting in Geneva. The limitation of accumulated dose suggested at the time corresponds roughly to a three-fold reduction in weekly dose, for example, in the case of whole body occupational exposure when the exposure takes place approximately at a constant rate.

(10) In practice the problem of chief concern is chronic exposure either at low dose rates or by intermittent small doses. Under these conditions it is reasonable to assume that the dose accumulated over a period of years is the controlling factor, *provided* the intermittent

doses are sufficiently small. Thus, in addition to limiting the accumulated dose it is necessary to limit the magnitude of a single dose (that is, a dose received in a short interval of time). Previously a single exposure equal to the maximum permissible weekly dose ("seven consecutive days") was permitted. Following the same pattern, the single dose limit for occupational exposure recommended in the present report is expressed in terms of the maximum permissible dose accumulated in a period of "13 consecutive weeks". The recommended value for the relevant organ (e.g. 3 rems for the blood-forming organs) has been made as high as it appears prudent, in the light of present knowledge. The stipulation of any 13 *consecutive* weeks has been made to make sure that operations are carried out in such a way that intermittent doses approximating the full 13 week quota do not occur at short intervals.

(11) In the recommendations published in 1955 maximum permissible limits were set on the basis of doses received by certain organs and certain serious late effects known to occur in them with sufficiently large doses. Provisions were made by means of an arbitrary "dose distribution curve" (in the report of Committee I) to limit the dose in other organs and tissues. This was made necessary by the adoption of a maximum permissible dose for the skin twice as large as that for the blood-forming organs (with an assumed effective depth of 5 cm). In the present report separate recommendations are made for three groups of organs or tissues:

- (a) Blood-forming organs, gonads and lenses of the eyes.*
- (b) Skin and thyroid gland.
- (c) All other organs or tissues, specifically as regards exposure essentially limited to the organ or tissue in question.

(12) For the blood-forming organs, gonads and the lenses of the eyes* the limits for occupational exposure are set in terms of the dose accumulated at various ages, according to the formula $D = 5(N - 18)$, where D is

the dose in rems and N is the age in years, with the additional stipulation that the dose accumulated during any 13 consecutive weeks shall not exceed 3 rems.

(13) For the skin and the thyroid gland the limit for occupational exposure is set in terms of the dose accumulated during any 13 consecutive weeks, and the recommended value is 8 rems. This is derived from an average of 0.6 rem/week (the maximum permissible weekly dose formerly recommended for the skin of the whole body) which in 13 weeks amounts to 7.8 rems, and the nearest whole number is used to avoid the implication of greater accuracy than is warranted by present knowledge. The limit for the dose in these tissues accumulated in 1 year is $(0.6 \times 50) = 30$ rems. It should be noted that the new recommendation refers to the dose in the skin itself, irrespective of the dose distribution in the subcutaneous tissues. Therefore, the comparison should be made with the previous recommendation for exposure to radiation of very low penetrating power, for which the recommended limit was 1.5 rem/week. Accordingly, in this case also a reduction has been made in the accumulated dose, but the single exposure limit has been increased from 1.5 to 8 rems. This should provide more flexibility in practice than was possible formerly.

(14) For all organs and tissues of the body except the blood-forming organs, the gonads and the lenses of the eyes,* the limit for occupational exposure is set in terms of the dose accumulated during any 13 consecutive weeks. With the exception of the skin, the pertinent practical cases in this category relate to exposure from internal sources essentially limited to individual organs or tissues. The following points require consideration. Whereas in the case of the blood-forming organs, the gonads, the lenses of the eyes* and the skin, the objective of protection is to prevent or minimize definitely known types of injury, in the case of other organs the type of injury is not known. (Bone constitutes the only exception, in which case the relevant injury is cancer and permissible limits may be set on the basis of data furnished

* See footnote to paragraph 27.

by human subjects who accumulated radium in their skeletons.) Possibly, radiation in sufficient dosage may increase the incidence of cancer in one of these organs (e.g. the thyroid gland) or it may accelerate aging of the organ. In the absence of factual data, it was deemed prudent in earlier recommendations of the Commission to set the maximum permissible limit for these organs, when irradiated by internal sources, as low as that for the more sensitive organs such as the gonads, that is, 0.3 rem/week. When the exposure is essentially limited to *one organ* because of the more or less selective accumulation of a certain radioactive isotope therein, it is obvious that this limit embodies a factor of safety not present when the *whole body* is exposed at the same permissible limit. For this reason and the fact that none of these organs is known to be as sensitive as the blood-forming organs, the gonads and the lenses of the eyes,* the Commission has decided to retain the previously recommended maximum permissible dose of 0.3 rem/week for each organ singly (with some exceptions noted in the report of Committee II). However the limit is now expressed in terms of 13 consecutive weeks, which makes it 4 rems, in round figures, with an annual accumulated dose of 15 rems. Committee II has made the necessary adjustments to conform with the lower permissible limits now recommended for some organs and for what may be regarded as constituting "whole body" exposure (e.g. isotopes distributed throughout the body, or several isotopes present simultaneously, each concentrating significantly in a different organ).

(15) The Commission has given particular attention to the difficult problem of setting permissible limits for exposure of persons in the neighborhood of radiation installations. The chief obstacle is the almost complete lack of knowledge of the deleterious effects that may result from low level exposure starting at conception and continuing throughout life. It is reasonable to expect a more marked effect then in the case of exposure starting after the individual has reached maturity (for one thing,

because the period of exposure is longer), but it is very difficult to decide what allowance to make. Guidance could be obtained from suitable experiments carried out with mammals and it is hoped that such studies will be undertaken soon in some laboratories. In the meantime caution is in order. The Commission recommends that provisions be made in a controlled area or areas to make sure that under normal operating conditions no child residing outside such controlled areas, receives more than 0.5 rem/year (in the appropriate organs) from radiation or radioactive material originating in the controlled area or areas. In practice it may be expected that while fluctuations in exposure rate would occur, they would not be such as to require special limitations. It will be noted that this is one-tenth of the *lowest* annual dose in any organ permitted for occupational exposure. It includes contributions made by external and internal sources but does not include doses contributed by natural background radiation or medical procedures.

(16) Special groups of *adults* in the vicinity of a controlled area are permitted to receive larger annual doses in the gonads, the blood-forming organs and the lenses of the eyes, by a factor of three (i.e. 1.5 rems). No biological significance should be attached to the magnitude of this factor, since present radiobiological information is grossly inadequate in this respect. The value recommended (1.5 rems/year) is one-tenth of the former maximum permissible annual dose for occupational exposure, on the basis of 0.3 rem/week in the most sensitive organs.*

(17) Planning for the future expansion of nuclear energy programs and the more extensive uses of radiation, requires measures intended to protect whole populations. Genetic damage is of greatest concern in this regard. The problem has been discussed by various national and international groups and tentative suggestions have been made. The Commission considered the problem at its 1956 meeting and later issued a statement in general terms.

* See footnote to paragraph 27.

* See also paragraphs 54 and 55.

However, recommendations in quantitative terms are needed in the design of power plants and other radiation installations and particularly in making plans for disposal of radioactive waste products. It is of the utmost importance in this connection to make sure that nothing is done now that may prove to be a serious hazard later, which cannot be corrected at all or will be very expensive to correct. The Commission is aware of the fact that a proper balance between risks and benefits cannot yet be made, since it requires a more quantitative appraisal of both the probable biological damage and the probable benefits than is presently possible. Furthermore, it must be realized that the factors influencing the balancing of risks and benefits will vary from country to country and that the final decision rests with each country (insofar as operations within one country do not affect other countries).

(18) The Commission wishes to point out that it is important to assign quotas of a maximum permissible genetic dose to the different modes of exposure, in order to make sure that those responsible for the control of exposure in one category do not take up a disproportionate share of the permissible total in their planning. However, at this time it is deemed best not to assign rigid quotas. As a tentative guide an illustrative apportionment is appended to paragraph 65.

(19) Briefly, the suggested limit for the genetic dose was arrived at in the following manner: Estimates made by different national and international scientific bodies indicate that a per capita gonad dose of 6–10 rems accumulated from conception to age 30 from all man-made sources, would impose a considerable burden on society due to genetic damage, but that this additional burden may be regarded as tolerable and justifiable in view of the benefits that may be expected to accrue from the expansion of the practical applications of “atomic energy”. There is at present considerable uncertainty as to the magnitude of the burden (see for example the report of the United Nations Scientific Committee on the Effects of Atomic Radiation) and, therefore, it is highly desirable to keep the exposure of large populations at as low a

level as practicable, with due regard to the necessity of providing additional sources of energy to meet the demands of modern society. A genetic dose of 10 rems from all man-made sources is regarded by most geneticists as the absolute maximum and all would prefer a lower dose. In some countries the genetic dose from medical procedures has been estimated to be about 4.5 rems* (see *Report of Joint Study Made by ICRP/ICRU for the U.N. Scientific Committee*). Therefore, if the limit for the genetic dose from all man-made sources were set at 6 rems, the contribution from all sources, other than medical procedures, would be limited to 1.5 rems in these countries. This would impose unacceptable restrictions on these countries. Accordingly, as a matter of practical necessity the Commission recommends that medical exposure be considered separately and that it be kept as low as is consistent with the necessary requirements of modern medical practice. The joint study of ICRP/ICRU indicates that careful attention to the protection of the gonads would result in a considerable reduction of the genetic dose due to medical procedures without impairment of their value. In view of these considerations the Commission suggests a limit of 5 rems for the genetic dose from all man-made sources of radiation and activities, except medical procedures.

(20) At the present time the contribution to the genetic dose from all man-made sources (other than medical procedures) is small. With careful planning the rate of increase can be kept under control and the ultimate value of this contribution may never reach the suggested limit of 5 rems. Since the genetic dose from medical exposure in most countries is much lower than 4.5 rems and since in those countries in which it is high efforts are being made to reduce it, the total genetic dose from all man-made sources actually received by the world population may be expected to be considerably less than 10 rems, perhaps even less than 6 rems in the foreseeable future. Furthermore, if a thermonuclear reaction can be utilized as a source of power, the problem

* See also paragraph 70.

of radiation protection may be greatly simplified.

(21) The Commission is aware that compliance with the new recommendations may entail structural changes in some existing installations and/or changes in operative procedures. Since in fact the new recommendations are more restrictive because of the greater emphasis put on the dose accumulated over a long period of time, it is not essential that such changes be made immediately, although it is obviously desirable. As a practical guide it is suggested that the transition period during which the necessary changes would be made, should not exceed 5 years.*

B. BASIC CONCEPTS†

OBJECTIVES OF RADIATION PROTECTION

(23) Exposure to ionizing radiation can result in injuries that manifest themselves in the exposed individual and in his descendants: these are called somatic and genetic injuries respectively.

(24) Late somatic injuries include leukemia and other malignant diseases, impaired fertility, cataracts and shortening of life. Genetic injuries manifest themselves in the offspring of irradiated individuals, and may not be apparent for many generations. Their detrimental effect can spread throughout a population by mating of exposed individuals with other members of the population.

(25) The objectives of radiation protection are to prevent or minimize somatic injuries and to minimize the deterioration of the genetic constitution of the population.

CRITICAL ORGANS AND TISSUES

(26) The organs and tissues of the body exhibit varying degrees of radiosensitivity, and it is therefore necessary, for purposes of protection, to consider their radiosensitivity with

(22) The Commission wishes to point out again that the setting up of maximum permissible limits of occupational and non-occupational exposure (especially the latter) requires quantitative information not yet available about the risks and benefits of an expanded use of "atomic energy". For this reason the Commission will be glad to receive factual data and suggestions from those concerned with the production or utilization of ionizing radiation, so that as much pertinent information as possible may be available to it in its future deliberations.

respect to specific functions as well as the doses they receive. When this is done, some organs and tissues assume a greater importance, according to the circumstances under which they are irradiated. They are then said to be critical.

(27) In the case of more or less uniform irradiation of the *whole body*, the critical tissues are those tissues of the body that are most radiosensitive with respect to the ability of carrying out functions essential to the body as a whole. In this report these are taken to be the blood-forming organs, the gonads, and the lenses of the eyes.‡ In previous reports the skin was listed as a critical organ in the case of whole body exposure. The presentation of the recommendations in the present report is simplified by not designating the skin as a critical organ.

(28) In the case of irradiation more or less limited to *portions* of the body, the critical tissue is that tissue most likely to be permanently damaged either because of its inherent radiosensitivity, or because of a combination of radiosensitivity and localized high dose.

* It will be noted that this suggestion was made in 1958.

† Revised in 1962.

‡ In the 1958 Recommendations the blood-forming organs, the gonads and the lenses of the eyes were regarded as critical tissues in the case of whole body exposure. There is evidence indicating that the lens may be specially radiosensitive only to particulate radiation of high LET (e.g. neutrons having an energy of 1 MeV). On the evidence available at present the lens seems not to assume greater importance than other tissues when X-, gamma- and beta-radiations only are concerned (see paragraph 52c).

SIGNIFICANT AREAS AND VOLUMES

(28a) The Commission's 1955 recommendations (*Brit. J. Radiology*, Supplement 6) included a reference to the volume or area over which the dose should be averaged in the computation of maximum permissible tissue doses. This reference has not been republished in subsequent recommendations but it is recommended that the following principles should apply.

(28b) Within permissible dose ranges specified for occupational exposure, when the object of control is to reduce to a very low order of magnitude the risk of late effects (such as malignant change from an accumulated dose of radiation) it is justifiable to consider the average dose to the whole organ or tissue. This has practical advantages in that the significant volume can be taken as that of the organ or tissue under consideration. In fact, this principle has necessarily been used already in calculating permissible concentrations of radioactive nuclides in tissues.

(28c) When skin is contaminated with radioactive material, it is considered that the previous recommendation of a significant area of 1 cm² might be too restrictive. It is therefore recommended that the significant area in such cases be taken to be of the order of 30 cm². This is a practicable recommendation from the standpoint of procedures used to determine the degree of contamination of the skin.

(28d) In other cases of external exposure, especially when the distance to the source is very short or when the exposed area is very small, it would not be appropriate to recommend the dose to be assessed as the average over 30 cm²; for these cases it is recommended that the previous practice of referring to 1 cm² be maintained.

PERMISSIBLE DOSE

(29) Any departure from the environmental conditions in which man has evolved may entail a risk of deleterious effects. It is therefore assumed that long continued exposure to ionizing radiation additional to that due to natural radiation involves some risk. However, man cannot entirely dispense with the use of ionizing radiations, and therefore the problem

in practice is to limit the radiation dose to that which involves a risk that is not unacceptable to the individual and to the population at large. This is called a "permissible dose".

(30) The permissible dose for an *individual* is that dose, accumulated over a long period of time or resulting from a single exposure, which, in the light of present knowledge, carries a negligible probability of severe somatic or genetic injuries; furthermore, it is such a dose that any effects that ensue more frequently are limited to those of a minor nature that would not be considered unacceptable by the exposed individual and by competent medical authorities.

(31) Any severe somatic injuries (e.g. leukemia) that might result from exposure of individuals to the permissible dose would be limited to an exceedingly small fraction of the exposed group; effects such as shortening of life span, which might be expected to occur more frequently, would be very slight and would likely be hidden by normal biological variations. The permissible doses can therefore be expected to produce effects that could be detectable only by statistical methods applied to large groups.

(32) The permissible dose to the gonads for the *whole population* is limited primarily by considerations with respect to genetic effects (see paragraphs 58-65).

(32a) On the basis of the criteria indicated in paragraphs 29-32, the Commission has given recommendations with regard to the *maximum* dose which, still fulfilling the above requirements, should be permitted under various circumstances. The Commission has balanced as far as possible the risk of the exposure against the benefit of the practice, and has also considered the possible danger involved in remedial actions once the exposure has occurred. This dose has been called the *maximum permissible dose*.

(32b) The basis of the Commission's recommendations is that any exposure to radiation may carry some risk. The assumption has been made that, down to the lowest levels of dose, the risk of inducing disease or disability in an individual increases with the dose accumulated by the individual, but is small even at the maximum permissible levels recommended for

occupational exposure. This assumption is supported by the limited statistics available which indicate that for radiation workers of the last generation, exposed subject to the maximum permissible levels of that time, the risks of somatic effects are comparable with or less than those of the majority of other trades and professions, and would therefore be considered as not unacceptable. The Commission similarly considered the risk of somatic effects in individuals within certain population groups, and recommended maximum permissible levels for these individuals.

(32c) With regard to genetic effects, the Commission assumed that the genetic burden to a population will be proportional to the genetic dose received by that population (see paragraph 63 of the 1958 Recommendations). The Commission therefore recommended a maximum permissible genetic dose of 5 rems,* on the basis that the resulting burden to society would be "tolerable and justifiable in view of the benefits that may be expected to accrue from the expansion of the practical application of 'atomic energy'".

(32d) The implication of a maximum permissible dose is that it must be capable of being controlled. It is therefore clear that the Commission's recommended maximum permissible doses are appropriate for those conditions in which the levels can be controlled. However, in the case of accidents and of environmental contamination when exposures may not be subject to control, the concept of a fixed maximum permissible dose ceases to be meaningful. Instead, other considerations arise, such as the need to balance the risk from radiation against the risks of particular counter-measures. The principles upon which these risks might be assessed and balanced are still under consideration.

DOSE-RATE EFFECTS

(32e) *Somatic effects.* It has long been recognized that the effects of radiation may be

dependent not only on the accumulated dose received but also on the way in which this total is fractionated and on the dose-rate at which each fraction is given. This applies particularly to radiation of low LET such as X-rays, gamma-rays and beta-radiation which are by far the commonest radiations encountered in occupational practice at the present time. It appears possible on some theoretical and experimental grounds that when either the total dose or the dose-rate is very low any effects will be directly proportional to the total dose and independent of dose-rate. This assumption is implicit in past recommendations on permissible levels and although confirmatory proof is lacking it is believed to be a reasonable basis for assessment.

(32f) *Genetic effects.* A linear dose-effect relationship unaffected by dose-rate has been generally accepted in the past for gene-mutations. Recent experimental work has shown, however, that at intermediate and higher levels of dose-rate the number of mutations produced in test-subjects may not be independent of dose-rate. Because of the importance of the genetic effect the Commission has made a special survey of recent work. This survey indicates that evidence for dependence of mutation frequency on dose-rate comes at present almost entirely from a study of seven gene-loci in spermatogonial cells and oocytes of the mouse. For insects there is not yet clear evidence of a difference in effectiveness of acute and chronic doses that cannot be ascribed to selection. No general relationship appears therefore to hold for all species.

(32g) On the basis of the above, the Commission does not at present modify its recommendations to allow for dose-rate effects in man.

CATEGORIES OF EXPOSURE

(33) These recommendations are designed to limit not only somatic but also genetic effects; it is therefore necessary to reduce as much as possible the dose to the population as a whole, as well as to the individual. In general, doses resulting from all sources of ionizing radiation should be considered in the appraisal of possible biological damage. How-

* From all sources additional to natural background plus the lowest practicable contribution from medical exposure.

ever, practical considerations make it necessary to consider separately the doses resulting from two categories of exposure, namely :

- (a) Exposure to natural background radiation.
- (b) Exposure resulting from medical procedures.

(34) Natural background radiation varies considerably from locality to locality and the doses it contributes to the various organs are not well known. If maximum permissible limits recommended by the Commission included background radiation, the allowable contribution from man-made sources—which are the only ones that can be controlled—would be uncertain and would have to be different for different localities. Accordingly, doses resulting from natural background radiation are excluded from all maximum permissible doses recommended in this report.

(35) In medical procedures, exposure of the patient to primary radiation is generally limited to parts of the body, but the whole body is exposed to some extent to stray radiation. The contributions to the doses in various organs and the part played in the over-all effects on the individual are practically impossible to evaluate at the present time. The Commission recognizes especially the importance of the *gonad* doses resulting from medical exposure and the attendant genetic hazard to the population. Accordingly, it recommends that the medical profession exercise great care in the use of ionizing radiation in order that the gonad dose received by individuals before the end of their reproductive periods be kept at the minimum value consistent with medical requirements. However, individual doses resulting from medical exposure are excluded from all maximum permissible doses recommended in this report.

(36) The recommendations cover the following three categories* of exposed individuals :

* It should be noted that exposures within the first two categories as defined here correspond to the two classes of exposure used in the International Labour Office's Radiation Protection Convention, namely (1) Workers directly engaged in radiation work, and (2) Workers not directly engaged in radiation work.

The first category consists of individuals who are occupationally exposed to radiation.

The second category comprises adults who work in the vicinity of controlled areas or who enter controlled areas occasionally in the course of their duties, but who are not themselves employed on work involving exposure to radiation.

The third category consists of individual members of the population at large (including persons living in the neighborhood of controlled areas).

In addition to recommending maximum permissible doses for individuals, the Commission also gives separate recommendations about the average exposure to the population as a whole, determined by exposures of the individuals within the above categories (paragraphs 58–70c).

Occupational Exposure

(37) Exposure of an *individual* who normally works in a controlled area constitutes occupational exposure. Maximum permissible doses are set for the individuals in the small portion of the population that can be occupationally exposed (paragraphs 46–52). The contribution from this group to the genetic dose to the *population* as a whole is discussed in paragraph 65.

Exposure of Adult Workers not Directly Engaged in Radiation Work

(38) Adults who work in the vicinity of controlled areas or who enter controlled areas occasionally in the course of their duties may be exposed to radiation originating in the controlled area, even if they are not themselves employed on work which ordinarily involves exposure to radiation. This category may include women of reproductive age and individuals subject to other hazards, and for these reasons the maximum permissible dose to these individuals is set lower than for persons occupationally exposed (paragraphs 53–55). The contribution from this category to the genetic dose to the whole population is discussed in paragraph 65.

Exposure of Individual Members of the Population at Large

(39) Individual members of the population at

large may be exposed to radiation originating in a controlled area or to radiation that cannot be related to any specific controlled area; e.g. exposure from environmental contamination and widely distributed radiation sources such as wrist-watches, TV-sets and various applications of radioactive materials to be expected as a result of future expansion in the atomic energy field. As such exposure is not easily controlled, it will be impossible to ensure that a recommended maximum permissible individual dose is not exceeded in any single case. Where large numbers are involved, it will not be possible to examine the habits of every individual. A reasonable procedure would be to study a sample of the group involved and to set the environmental level so that no individual in the sample receives any excessive exposure. There will always remain the possibility that someone of grossly different habits from those in the observed sample may receive a higher dose than the maximum in the sample.

(40) In order to facilitate planning for the anticipated increased uses of nuclear energy and other sources of radiation, it is desirable at this time to recommend a maximum for the genetic dose to the *population* (paragraph 64); this maximum will determine what average gonad exposure could be allowed. Part of the recommended maximum genetic dose will have to be used for occupational exposure, for exposure of adult workers not directly engaged in radiation work, and for medical exposure. The proper apportionment for exposure of the population at large must allow for both internal and external exposure (paragraph 65).

Medical Exposure

(41) No recommendations are given with regard to the dose to the individual from medical

exposure. (The contribution of medical exposure to the genetic dose is discussed in paragraphs 69–70c.)

REDUCTION IN MAXIMUM PERMISSIBLE DOSE

(42) The 1958 recommendations were introduced partly with the intention of limiting the genetically significant radiation exposure (see paragraph 63) of the population, and partly to limit the probability of somatic injury by reducing the lifetime dose. This reduction does not result from positive evidence of damage due to the use of the earlier permissible dose levels, but rather is based on the concept that biological recovery may be minimal at such low dose levels.

TIME INTERVAL OVER WHICH DOSE IS TO BE ASSESSED

(43) The maximum permissible weekly doses recommended by the Commission in 1950 were replaced in 1958 by limits for the doses received over longer periods of time (paragraphs 47–49). In the case of occupational exposure the maximum permissible dose that may be accumulated at a certain time depends on the age of the worker. The dose to individuals in the population at large, or in special groups other than occupational, may be accumulated at a rate that is determined by a maximum permissible annual dose. The genetic dose to the whole population is assessed over the period between conception of the individual and conception of each child of the individual. (See paragraph 63 for method of evaluation.)

(44) These extended periods of time allow for some flexibility in the way in which radiation exposure may be received, and at the same time provide what is considered to be adequate protection for each group of the population.

C. MAXIMUM PERMISSIBLE DOSES*

GENERAL

(45) It is emphasized that the maximum permissible doses recommended in this section are *maximum* values; the Commission recom-

mends that all doses be kept as low as practicable, and that any unnecessary exposure be avoided.

* Revised in 1962.

EXPOSURE OF INDIVIDUALS

OCCUPATIONAL EXPOSURE

(46) In any organ or tissue, the *total* dose due to occupational exposure shall comprise the dose contributed by external sources during working hours and the dose contributed by internal sources taken into the body during working hours. It shall not include any medical exposure or exposure to natural radiation. The Commission wishes to emphasize that "medical exposure" refers to the exposure of *patients* that is necessary for medical purposes and *not* to the exposure of the personnel conducting such procedure.

Exposure of the Gonads and the Blood-forming Organs

(47) The maximum permissible total dose accumulated in the gonads and the blood-forming organs at any age over 18 years shall be governed by the relation

$$D = 5(N - 18)$$

where D is tissue dose in rems and N is age in years.

(48) For a person who is occupationally exposed at a constant rate from age 18 years, the formula implies a maximum weekly dose of 0.1 rem. It is recommended that this value be used for purposes of planning and design.

Rate of Dose Accumulation

(49) To the extent the formula permits, an occupationally exposed person may accumulate the maximum permissible dose at a rate not in excess of 3 rems during any period of 13 consecutive weeks (i.e. in no 13 consecutive weeks shall the dose exceed 3 rems).† If necessary, the 3 rems may be received as a single dose, but as the scientific knowledge of the biological effects of differing dose-rates is scant, single doses of the order of 3 rems should be avoided as far as practicable.

(49a) *Exposure of women of reproductive age.* The recommendation for dose accumulation at rates up to 3 rems per quarter should not

apply in circumstances involving abdominal exposure of women of reproductive age. Women of reproductive age should be occupationally employed only under conditions where the exposure of the abdomen is limited to 1.3 rems in a 13 week period, corresponding to 5 rems per year delivered at an even rate. Under these conditions the dose to an embryo during the first two months of pregnancy would normally be less than 1 rem, a dose which the Commission considers to be acceptable.

(49b) *Exposure of pregnant women.* When a pregnancy has been diagnosed, arrangements should be made to ensure that the exposure of the woman be such that the average dose to her fetus during the remaining period of the pregnancy does not exceed 1 rem. Under conditions in which the fetal dose may approximate to that received by the woman, for example when the abdomen is exposed to penetrating radiation, this recommendation will normally be met if the woman is not exposed at rates greater than those applicable to adult workers not directly engaged in radiation work, since such workers may not be exposed at rates greater than 1.5 rems per year (see paragraph 54).

(49c) Under conditions in which the fetal dose will be considerably less than that received by the woman, as for example when working with diagnostic X-ray equipment of 150 kV or less, or where the abdomen is protected from or not exposed to the radiation, the recommendation may be satisfied by continuing occupational exposure of the woman at a rate not exceeding 1.3 rems per 13 weeks.

*Application to Special Cases**

(50) Setting permissible limits of exposure in terms of the dose accumulated up to a given age introduces certain practical complications. Thus, some workers (previously exposed at levels within the then permissible limits) may have already accumulated a dose in excess of the maximum permitted by the formula. There

† A calendar 13 week period starting at any chosen date may be used instead of a period of 13 consecutive weeks if there is no reason to suppose that doses are being accumulated at grossly irregular rates.

* Paragraphs 50 to 51e are reproduced from the 1958 Recommendations of the Commission.

are also special cases in which exceptions in the application of the formula may be desirable for practical reasons and are justifiable within the context of paragraph 42. The following recommendations are intended to provide guidance on administrative policy, which may well vary according to circumstances at the local level. (It should be noted that this situation will obtain only during a relatively short transition period.)

(51a) *Previous exposure history unknown.* When the previous occupational exposure history of an individual is not definitely known, it shall be assumed that he has already received the full quota permitted by the formula.

(51b) *Persons exposed in accordance with the former maximum permissible weekly dose.* Persons who were exposed in accordance with the former maximum permissible weekly dose of 0.3 rem and who have accumulated a dose higher than that permitted by the formula, should not be exposed at a rate higher than 5 rems in any one year, until the accumulated dose at a subsequent time is lower than that permitted by the formula.

(51c) *Persons starting work at an age of less than 18 years.* When a person begins to be occupationally exposed at an age of less than 18 years, the dose shall not exceed 5 rems in any one year under age 18, and the dose accumulated to age 30 shall not exceed 60 rems. (The minimum age at which occupational exposure is legally permitted is lower than 18 years in some countries.)

(51d) *Accidental high exposure.* An accidental high exposure that occurs *only once in a lifetime* and contributes no more than 25 rems shall be added to the occupational dose accumulated up to the time of the accident. If the sum then exceeds the maximum value permitted by the formula, the excess need not be included in future calculations of the person's accumulated dose. Accidental exposure to doses higher than 25 rems must be regarded as being potentially serious, and shall be referred to competent medical authorities for appropriate remedial action and recommendations on subsequent occupational exposure. This is intended as an administrative guide to permit the continuation

of work with radiation, following a bona fide accident ("once in a lifetime"), in cases in which interruption of such work, or curtailment of exposure, would handicap the individual in the pursuit of his career.

(51e) *Emergency exposure.* Emergency work involving exposure above permissible limits shall be planned on the basis that the individual will not receive a dose in excess of 12 rems. This shall be added to the occupational dose accumulated up to the time of the emergency exposure. If the sum then exceeds the maximum value permitted by the formula, the excess shall be made up by lowering the subsequent exposure rate so that within a period not exceeding 5 years, the accumulated dose will conform with the limit set by the formula. Women of reproductive age shall not be subjected to such emergency exposure.

Exposure of Single Organs other than the Gonads and the Blood-forming Organs

(52) For exposure that is essentially restricted to portions or single organs of the body, with the exception of the gonads and the blood-forming organs, a higher dose than the one derived from the formula $D = 5(N - 18)$ is permitted. The following recommendations are made.

(52a) *A maximum dose of 8 rems/13 weeks for the skin, thyroid and bone.** The maximum dose in the skin, thyroid and bone, accumulated over any 13 consecutive weeks, shall not exceed 8 rems. This recommendation applies to all exposure of the skin, except the skin of the hands and forearms, feet and ankles (see paragraph 52b). As the 8 rems are derived from an average of 0.6 rem/week, the annual dose for a 50 week year is limited to 30 rems.

(52b) *A maximum dose of 20 rems/13 weeks for the hands and forearms, feet and ankles.* In the case of exposure of the hands and forearms, feet and ankles, the maximum dose accumulated over any 13 consecutive weeks shall not exceed 20 rems. This recommendation applies to all tissues of the above-mentioned extremities. As the 20 rems are derived from an average of

* The dose to bone is based on a body-burden of $0.1 \mu\text{C}$ of Ra^{226} (see Report of Committee II, ICRP Publication 2).

1.5 rems/week, the annual dose for a 50 week year is limited to 75 rems.

(52c) *A maximum dose of 4 rems/13 weeks for limited exposure of internal organs* other than the thyroid, the gonads and the blood-forming organs.* In the case of internal organs, limited exposure originates almost exclusively from radioisotopes within the body. As most planning of release of radioactive isotopes to the air and water supplies in controlled areas is made under conditions where occupational groups rather than single individuals are exposed, a formula corresponding to the one given in paragraph 47 cannot in general be applied to internal exposure. An average of 0.3 rem/week in the organ of interest (with some exceptions noted in the report of Committee II) is expected to be maintained under equilibrium conditions if the concentration in air or water of the relevant isotope is kept at levels given in the tables in the report of Committee II. Variations of the dose-rate will occur in practice, and are permissible, provided that the dose accumulated over any 13 consecutive weeks does not exceed 4 rems. As this maximum is derived from a weekly average of 0.3 rem, the annual dose for a 50 week year is limited to 15 rems. In the case of irradiation of the lens of the eye with particulate radiation of high LET (e.g. neutrons having an energy of 1 MeV) a special *QF* of 30 shall be used, instead of the usual value of 10.

(52d) *Whole body exposure from uptake of several radioisotopes.* When the radioactive isotopes in a mixture are taken up by several organs and the resultant tissue doses in such organs are of comparable magnitude, the combined exposure is considered to constitute essentially whole body exposure. Accordingly, the permissible levels of exposure will be those applicable to the gonads and the blood-forming organs.

(52e) *Short-term exposures to radioactive materials.* One or more short-term exposures to radioactive materials within a period of 13 consecutive weeks is considered acceptable if the total intake of radioactive material during this period does not exceed the cumulative intake

allowed when exposure occurs for 13 weeks at the maximum levels (MPC values) for occupational exposure given in the Report of Committee II (ICRP Publication 2). If significant exposure to external sources occurs concurrently, the quarterly intake referred to above should be estimated to make allowance for the dose equivalent delivered by external sources (ICRP Publication 2, page 24). The 50 year integrated dose to the critical organ from such an intake will not exceed 1.3 rems for the whole body, blood-forming organs or gonads, 8 rems for skin, thyroid and bone,* and 4 rems for other organs.

(52f) *Chemical toxicity.* Because of the toxicity of natural uranium, U^{238} , U^{236} , or U^{235} in soluble form in amounts permitted according to the above on the basis of radiological protection, the inhalation of uranium of any isotopic composition should not exceed 2.5 milligrams of soluble uranium in one day, or the ingestion averaged over 2 days should not exceed 150 milligrams of soluble uranium.† For insoluble forms of uranium, maximum intake shall be limited by the same rule that applies to other radioactive materials set forth above. Because of the low specific activity of certain other radioactive materials with very long radioactive half-lives (e.g. Rb^{87} , In^{115} , Nd^{144} , Sm^{147} , Re^{187} , etc.), the mass or chemical toxicity will in general determine maximum rates of intake. Similar considerations will apply also to the values given in Table 1 of ICRP Publication 2.

(52g) *Accidental high exposure to radioactive materials.* In the case of an accidental high exposure to radioactive materials where the total intake of radioactive material exceeds the amount that would result from intake for 1 year at the maximum levels for occupational exposure

* The dose to bone is based on a body-burden of $0.1 \mu c$ of Ra^{226} (see Report of Committee II, ICRP Publication 2).

† This restriction on the ingestion of soluble forms of uranium revises the maximum permissible concentration recommended in Table 1 of ICRP Publication 2 for the continuous ingestion of drinking water. The new values of MPC for uranium that result from taking into account the chemical toxicity of uranium are given in Part 5 of ICRP Publication 6.

* Including the lens of the eye.

to such radioactive materials given in the Report of Committee II (ICRP Publication 2), an estimate of the intake resulting from the exposure shall be entered on the individual's record and he shall be referred to competent medical authorities for appropriate action.

(52h) *Emergency work involving exposure to radioactive materials.* Emergency work involving exposure to radioactive materials at levels above the normal maximum permissible concentrations shall be planned on the basis that the total intake of radioactive material during the emergency period should not exceed the cumulative intake that would result from exposure for 1 year at the maximum levels (MPC values) for occupational exposure to such radioactive materials given in the Report of Committee II (ICRP Publication 2). If significant exposure to external sources might be expected to occur concurrently, the annual intake referred to above should be estimated to make allowance for the dose equivalent delivered by the external sources (ICRP Publication 2, page 24). The 50 year integrated dose to the critical organ from such an intake will not exceed 5 rems for the whole body, blood-forming organs or gonads, 30 rems for skin, thyroid and bone,* and 15 rems for other organs. When such an exposure has occurred, an estimate of the intake shall be entered in the individual's record, and action shall be taken appropriate to paragraphs 86 and 86a.

ADULT WORKERS NOT DIRECTLY ENGAGED IN RADIATION WORK

(53) In any organ or tissue, the total maximum permissible individual dose shall consist of the sum of the doses contributed by both external and internal sources. It shall not include any medical exposure or exposure to natural radiation.

EXPOSURE OF POPULATION†

GENERAL

(58) Proper planning for nuclear power programs and other peaceful uses of atomic energy on a large scale requires a limitation of

(54) For adult workers not directly engaged in radiation work (see paragraph 36) the total annual dose, including contributions from external and internal sources, to the gonads and the blood-forming organs, shall not exceed 1.5 rems, nor shall the contribution from a mixture of isotopes whose combined exposure constitutes essentially whole body exposure, make the total annual dose exceed 1.5 rems.

(55) The annual dose to all other organs and tissues, and to the hands and forearms, feet and ankles, shall be limited to one-tenth of the corresponding annual occupational doses.

INDIVIDUAL MEMBERS OF THE POPULATION AT LARGE

(56) In any organ or tissue the total maximum permissible individual dose shall consist of the sum of the doses contributed by both external and internal sources. It shall not include any medical exposure or exposure to natural radiation.

(57) The population at large contains children, for whom it is considered that a lower dose to the gonads and the blood-forming organs should apply. The maximum total dose limit for individuals in the population at large shall be 0.5 rem per year to the gonads and the blood-forming organs, nor shall the contribution from a mixture of isotopes whose combined exposure constitutes essentially whole body exposure make the total annual dose exceed 0.5 rem.

(57a) The annual dose to all other organs and tissues and to the hands and forearms, feet and ankles, shall be limited to one-tenth of the corresponding annual occupational doses. This recommendation applies to exposures for which control can be exercised. In the case of accidents and of environmental radiation beyond regular control, special considerations arise (see the above discussion on permissible dose).

the exposure of whole populations, partly by limiting the individual doses and partly by limiting the number of persons exposed.

(59) This limitation necessarily involves a

* The dose to bone is based on a body-burden of $0.1 \mu\text{C}$ of Ra^{226} (see Report of Committee II, ICRP Publication 2).

† This section deals with exposures averaged over whole populations.

compromise between deleterious effects and social benefits. Consideration of genetic effects plays a major role in its evaluation. The problem has been discussed extensively in recent years and suggestions have been made by different national bodies. The Commission is aware of the fact that a proper balance between risks and benefits cannot yet be made, since it requires a more quantitative appraisal of the probable biological damage and the probable benefits than is presently possible. Furthermore, it must be realized that the factors influencing the balancing of risks and benefits will vary from country to country and that the final decision rests with each country.

(60) Because of the urgent need for guidance in this regard, the Commission in its 1958 Recommendations suggested an interim ceiling for the exposure of the whole population. The proposed level is essentially in accordance with suggestions by other scientific groups that have studied the problem and tried to evaluate the possible biological effects. It is felt that this level provides reasonable latitude for the expansion of atomic energy programs in the foreseeable future. It should be emphasized that the limit may not in fact represent the proper balance between possible harm and probable benefit, for reasons already mentioned.

(61) On the assumption that the genetic effects are linearly related to the gonad dose and provided that no threshold dose exists, it is possible to define a population dose average that is relevant to the assessment of genetic injury to the whole population (paragraphs 62–63). In the case of somatic effects no such dose can easily be defined although the annual per capita dose to certain tissues or to the whole body may be relevant on the assumption of a non-threshold, linear dose-effect relation.

GENETIC DOSE

Assessment of Genetic Dose

(62) The genetic dose to a population is the dose which, if it were received by each person from conception to the mean age of childbearing, would result in the same genetic burden to the whole population as do the actual doses received by the individuals. A permissible genetic dose

is that dose, which if it were received by each person from conception to the mean age of childbearing, would result in an acceptable burden to the whole population.

(63) The genetic dose to a population can be assessed as the annual genetically significant dose multiplied by the mean age of childbearing, which for the purpose of these recommendations is taken to be 30 years. The annual genetically significant dose to a population is the average of the individual gonad doses, each weighted for the expected number of children conceived subsequent to the exposure.

Maximum Permissible Genetic Dose

(64) It is suggested that the genetic dose (see paragraph 63) to the whole population from all sources additional to the natural background should not exceed 5 rems plus the lowest practicable contribution from medical exposure. The background is excluded from the suggested value because it varies considerably from country to country. The contribution from medical exposure is considered separately for the same reason and also because the subject is being studied for the purpose of limiting such exposure to the minimum value consistent with medical requirements.

Apportionment of Genetic Dose

(65) The suggested maximum genetic dose of 5 rems in addition to the dose from medical procedures and natural background must not be used up by one single type of exposure. The proper apportionment of the total will depend upon circumstances which may vary from country to country, and the decision should therefore be made by national authorities.

Addendum to Paragraph 65

(a) *Illustrative apportionment.* The Commission does not wish to make any firm recommendations as to the apportionment of the genetic dose of 5 rems but, for guidance, gives the following apportionment as an illustration:

Occupational exposure	1.0 rem
Exposure of adult workers not directly engaged in radiation work	0.5 rem

Exposure of the population at large .. 2.0 rem
Reserve 1.5 rem

(b) *Fractions of population.* Assuming that the ratio of the total population to the reproductive population is the same in all groups, the largest fraction (ε) of the whole population that can be exposed to an average annual dose D_1^i is given by the equation:

$$\varepsilon \cdot 30 \cdot \bar{D}_1^i = D_{30}^i$$

where D_{30}^i is the apportionment of the genetic dose to the i th exposure group, and the average annual dose within the group can be expressed as a fraction of the maximum permissible individual annual dose; i.e. $\bar{D}_1^i = F_1 D_1^i$.

(c) *Occupational exposure.* Assigning 1.0 rem to occupational exposure would mean that 0.7 per cent of the whole population could accumulate the maximum permissible occupational gonad dose of 60 rems by age 30. It is very unlikely that such a figure will be approached in the foreseeable future. At the present time, the number of persons occupationally exposed in technologically developed countries is about 0.1–0.2 per cent of the population, and most of these persons receive doses which are considerably less than the maximum permissible doses.

(d) *Exposure of adult workers not directly engaged in radiation work.* An apportionment of 0.5 rem for the exposure of adult workers not directly engaged in radiation work would imply that about 1 per cent of the population could receive the maximum permissible individual annual gonad doses for these individuals. The allowable size of this group varies inversely with the average dose within the group. Thus, if this dose were only 10 per cent of the maximum individual doses, the group could amount to 10 per cent of the whole population, which is larger than is likely to occur.

(e) *Exposure of the population at large.* The apportionment of 2.0 rems (with a long-term reserve of 1.5 rems for possible eventualities) for the genetic exposure of the population at large is intended for planning purposes in the development of nuclear energy programs (with the associated waste disposal problems) and more extensive uses of radiation sources. In the case of internal exposure, the radioisotopes of interest are those that contribute to the gonad dose directly (by local concentration) or indirectly (by radiation produced elsewhere in the body). In either case the maximum permissible

concentrations in air and water of these isotopes recommended by Committee II for continuous occupational exposure ("168 hour week") are based on an average yearly dose of 5 rems in the gonads or the whole body. If for these isotopes the average concentrations in public air and water supplies are lower than the values recommended for continuous occupational exposure by a factor of 1/100, the genetic dose to the population would amount to 1.5 rems ($5 \times 1/100$ rems/year in the gonads $\times 30$ years = 1.5 rems). In this case the contribution from external sources should be limited to 0.5 rem in order not to exceed the total of 2 rems.

SOMATIC DOSE

(66) No specific recommendations are made at this time as to the maximum permissible "somatically" relevant dose to the population. However, it is expected that the maximum permissible limits of the *individual* total doses recommended in paragraphs 46–57a will keep the average dose in any tissue at such a level that the injuries that could possibly occur in a population would be well within acceptable limits (see paragraph 31).

(67) In the case of external exposure of the whole body to penetrating radiation the restriction imposed by the genetic dose to the population automatically reduces the doses to internal organs below the *individual* maximum permissible annual doses recommended in paragraphs 46–57a. Thus the probability of somatic injury in these organs is considerably lower than indicated in paragraph 66. The same thing applies to internal exposure resulting from radioisotopes that directly or indirectly contribute to the gonad dose of a population (see addendum to paragraph 65).

(68) There remain for further consideration those isotopes that concentrate in specific organs (other than the gonads). In view of the existing uncertainty as to the dose-effect relationships for somatic effects, it is suggested that for planning purposes the average concentrations of such isotopes, or mixtures thereof, in air or water, applicable to the population at large, should not exceed one-thirtieth of the MPC values for continuous

occupational exposure given in the report of Committee II.*

MEDICAL EXPOSURE

Radiological Examinations of Women of Reproductive Age

(69) The Commission wishes to call attention to reports of embryonic and fetal sensitivity to ionizing radiation and to emphasize that the possibility of pregnancy must be taken into account by the attending physician when deciding on radiological examinations that involve the lower abdomen and pelvis of women of reproductive age. The Commission also wishes to point out that the 10-day interval following the onset of menstruation is the only time when it is virtually certain that women of such age are not pregnant. Therefore, it is recommended that all radiological examinations of the lower abdomen and pelvis of women of reproductive age, that are not of importance in connection with the immediate illness of the patient, be limited in time to this period when pregnancy is improbable. The examinations that should be delayed to await the onset of the next menstruation are those that could without detriment be delayed till the conclusion of a pregnancy or at least until its latter half.

Apportionment of Total Genetic Dose—Medical Exposure

(70a) In the 1958 Recommendations (para-

graph 70) the Commission referred to the upper limit of the estimates of the annual genetically significant dose from medical exposure, and noted that the highest levels could be reduced significantly by careful attention to techniques.

(70b) More recent estimates of the genetic dose from medical exposure, described in the 1962 Report of UNSCEAR,[†] indicate that the actual dose may be considerably less than the highest levels referred to above. In addition, the 1962 UNSCEAR Report referred to estimates, which have been made in two countries, of the extent by which a reduction in dose could be achieved without loss of necessary medical information.[‡]

(70c) Paragraph 70 of the 1958 Recommendations concluded: "A certain allowance for medical exposure of populations must be made and may be made in the near future as the subject is being studied for the purpose of limiting such exposure to the minimum value consistent with medical requirements". It is clear that the permissible dose will depend upon the value of the medical benefit to be derived, and future extensions in the use of radiological methods may confer greater benefit from their application than detriment from the necessary associated exposure to radiation. At the present time the Commission has decided to maintain its policy of not making numerical recommendations with regard to the appropriate genetic dose from medical exposures.

D. GENERAL PRINCIPLES REGARDING WORKING CONDITIONS§

RESPONSIBILITY

(70d) The owner or the person in charge of a controlled area shall be responsible for the working conditions and for the instruction of

all persons working in the area regarding radiation hazards and methods of control. He shall be responsible for maintaining radiation levels outside the controlled area resulting from

* The basis for the limits of permissible exposure of populations to man-made sources of ionizing radiations is the dose received by the various organs of the body and not the MPC values, or other criteria by which the dose is controlled. Nevertheless, for planning purposes some guidance as given in paragraph 68 must be available. The word "average" in paragraph 68 refers to the concentration of radioactive nuclides, averaged over a year, in the total intake to the average person of the population.

[†] Estimates of the annual genetically significant dose from X-ray diagnosis in 14 countries ranged from 6 to 60 mrem.

[‡] Ministry of Health, Department of Health for Scotland, Radiological Hazards to Patients. Second Report of the Committee. HMSO (1960).

LARSSON, L.-E. *Acta Radiologica*, Supplement 157: 7-127 (1958).

§ Reproduced from the Commission's 1958 Recommendations with the addition of paragraphs 84a and 86a.

operations within the area so that exposures do not exceed the maximum permissible doses recommended in paragraphs 53–57a.

(71) A controlled area shall be established where persons occupationally exposed could receive doses in excess of 1.5 rems/year.

(72) A controlled area is an area in which the exposure of personnel to radiation or radioactive material is under the supervision of a radiation protection officer.

(73) A radiation protection officer is one who has the knowledge and responsibility to apply appropriate radiation protection regulations. He may be the owner or the person in charge of the controlled area or he may be a technically competent person appointed by the above.

(74) A qualified expert (or health physicist) is a person having the knowledge and training needed to measure ionizing radiations and to advise regarding radiation protection. The qualification should be of the type specified by a National Committee.

RADIATION SURVEYS AND MONITORING

Surveys Prior to Use of Controlled Areas

(76) In those instances where the operations in a controlled area may disturb or alter significantly the environment with respect to radiation hazards, adequate surveys should be made of the radioactivity of the air, soil and water prior to the start of operations. This will provide a base line from which to judge the adequacy of radiation controls within the area.

(77) During and after installation, appropriate radiation surveys shall be made to ensure that the pertinent recommendations will be complied with when routine operations commence. Routine operations shall be deferred until such compliance is assured.

(78) When additional operations are planned in the area, a thorough survey should be made of the background radiation prior to the start of the new operations. This will aid in the identification of the operation responsible for any increase of the background radiation or the contamination in the area.

Routine Surveys and Monitoring

(79) Radiation surveys shall be made regularly, at a frequency dictated by the operations within the area, to determine the adequacy of safety procedures. This should include checks of the facilities, equipment (radiation warning devices, radiation shields, hoods, respirators, ventilating system, etc.), and working techniques. When there is any reasonable probability of a radiation hazard existing, the vicinity of the controlled area should also be surveyed.

Special Surveys

(80) Specific and detailed recommendations regarding radiation surveys applicable to some special cases are given in the Reports of the Committees of ICRP.

HEALTH SURVEILLANCE

Pre-employment Examination

(81) All new personnel in radiation work shall have a pre-employment medical examination. Notes should be made of the family history, of the previous occupational history, and of previous X-ray diagnostic examination or radiation therapy. The examination shall include a complete blood count, with determination of erythrocyte and leukocyte levels and a differential white cell count. It should be recognized that the examination is directed toward determining the “normal” condition of the worker at the time of employment, and toward noting any abnormalities that might later be confused with radiation damage.

(82) In cases where there has been previous occupational exposure, the total accumulated dose shall be recorded (see paragraphs 47–51) and any appropriate additional medical examinations performed. These should include ophthalmological examinations, with particular reference to changes in the lens, in cases of exposure to neutrons and to heavy particles, and examinations of skin and nails in the case of partial external irradiation and external contamination.

Routine Medical Examinations

(83) Medical examinations should be performed at a frequency depending upon the conditions of the occupational exposure. Blood counts, although they are a part of a medical examination, are not to be considered as a method of radiation monitoring.

(84) Persons occupationally exposed to neutrons and to heavy particles of significant penetration should have ophthalmological examinations, with particular reference to changes in the lens. The frequency of the examination will depend upon the conditions of exposure.

Occupational Working Hours and Length of Vacation

(84a) The Commission considers that with the present maximum permissible exposure levels no special treatment of radiation workers with respect to working hours and length of vacation is needed.

PERSONNEL MONITORING

External Radiation

(85) Doses received as a result of occupational exposures shall be systematically checked with appropriate instruments to ensure that the maximum permissible doses are not exceeded and to make it possible to keep individual cumulative dose records.

Internal Radiation

(86) Tests should be performed to estimate the total body-burden for workers who deal with unsealed radioactive isotopes that may give rise to levels of ingestion or inhalation in excess of the maximum permissible concentrations. Such tests should also be performed where radioisotopes may enter the body through the skin or through skin punctures and open wounds. These tests may require the monitoring of breath and excreta, and the direct determination of the body-burden by means of a total body monitor, according to circumstances. The radiation doses delivered to the appropriate organs or

tissues should be calculated and noted on the personal record, and the permitted doses of external radiation should be adjusted to allow for the "internal" doses.

Addition of Doses from External and Internal Exposures

(86a) The Commission has considered the difficulty of making proper allowance for the addition of doses from penetrating external exposure and from internal exposure *in the case of long-lived bone-seeking isotopes*, in view of the use for them of the "*n*" factor. For these radionuclides the Commission recommends that

(i) if the estimated body-burden is less than one-half of the maximum permissible, no consequential restriction of external radiation exposure need be applied;

(ii) if the estimated body-burden is greater than one-half but less than the maximum permissible, the total body exposure to penetrating external radiation shall be limited to not more than 1.5 rems in any year; and if *A* years is the age of the individual when the body-burden was first found to exceed one-half the maximum permissible, then the total accumulated dose from such future exposure beyond age *A* shall not exceed $1.5(N - A)$ rems where *N* is the current age of the individual; if, however, at age *B* the body-burden is found to have dropped to less than one-half the maximum permissible value, the accumulated dose from future external total body exposure beyond age *B* shall not exceed $5(N - B)$ rems.

(iii) if the estimated body-burden equals or exceeds the maximum permissible, no occupational exposure to penetrating external radiation is permissible.

RADIATION WARNING DEVICES

(87) An appropriate form of warning shall be provided to indicate the existence of a radiation hazard, even if the hazard is of a temporary nature only. In the latter case the warning device should be removed when the hazard no longer exists.